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Memoirs of the Department of Agriculture in India

The use of Hydrocyanic Acid Gas for the Fumigation of American Cotton on Import into India

Experiments on its Lethal Power for the Mexican Boll-Weevil (*Anthonomus grandis*), and for the Grain-Weevil (*Sitophilus oryzae*); on the Extent to which it is absorbed by Cotton and Jute respectively; and on a Practical Method for Satisfactory Fumigation on a Large Scale.

BY

A. JAMES TURNER, M.A., B.Sc.

Director, Technological Laboratory, Indian Central Cotton Committee, Bombay

AND

D. L. SEN, M.Sc. Tech., M.Sc., A.I.C.

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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FOREWORD

BY

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Secretary, Indian Central Cotton Committee.

Prior to the war India imported American cotton in varying amounts but averaging some 26,000 bales per annum. In 1920-21 such importations were again heavy and in view of the enormous damage caused by the Mexican Boll-Weevil in the United States, the question whether this pest might not find its way into India through the medium of imported baled cotton was raised by two Chambers of Commerce. Enquiries showed that there was a definite risk of the pest being so introduced and that if this happened the damage to the Indian crop might be incalculably great. A consideration of the known facts regarding the life history of *Anthonomus grandis* and a comparison of the climatic conditions of the Indian cotton-growing tracts with those of the American cotton belt lead inevitably to the conclusion that, once introduced, the Boll-Weevil would spread rapidly in India. Hence, in 1923, the Indian Central Cotton Committee recommended to the Government of India that in future American cotton should only be imported on the condition that it was fumigated with hydrocyanic acid gas at the port of entry. This fumigant was chosen because it was already in use in America, where all imported cotton is required to be fumigated in order to prevent the introduction of another pest (the Pink Bollworm), and because American experiments had shown that such fumigation had no deleterious effect on the spinning, dyeing and bleaching properties of cotton. Furthermore, the machine for the continuous generation and the control of hydrocyanic acid gas for fumigation purposes, designed by Col. Glen Liston, I.M.S., provides a safe and convenient method of carrying out fumigation. The commercial aspect of the question was examined by the Central Cotton Committee, and in view of the great variation in arrivals of American cotton in different seasons and the need of elasticity in any scheme for the fumigation of such cotton, it was decided to fumigate the cotton in barges.

This memoir describes the experimental work done by the Central Cotton Committee at the request of the Government of India to determine the conditions under which fumigation should be carried out and the safeguards necessary. In particular, it was necessary to ascertain the concentration of gas to be employed and the period of exposure necessary in order to ensure the destruction of the weevils. A feature of the experimental work, and of the commercial fumigation alike, is that the actual concentration of hydrocyanic acid gas in the atmosphere of the fumigating vessel, chamber, or barge, is determined with precision. Where insects with relatively high resisting powers have to be dealt with, this is a point of extreme importance for, as the results show, the actual concentration obtained may differ considerably from that calculated from the quantities of chemicals used.

From the 1st of December 1925, when the Government notification came into force, until the end of January 1927 approximately 89,000 bales of American cotton

have been fumigated in Bombay ; and as the arrangements have worked smoothly the *modus operandi* may be described briefly. The barge in which fumigation is to take place is sent alongside the ship and the cotton is discharged into it overside. The loaded barges are towed to the fumigation wharf, closed by special gas-tight hatch covers, the Liston machines placed on the barges and fumigation commenced. The operations at the fumigation wharf commence in the early morning, the application of the gas is continued throughout the day, and the barges remain under gas, with a falling concentration, during the night. Next morning the concentration of gas in the barge is determined with due precautions, the hatch covers are removed and after a sufficient period to allow of the dispersal of remaining gas, the barges are unloaded. In the ordinary routine of working each barge is turned round every three days. When arrivals are unusually heavy auxiliary barges for the transport of the cotton from the ship to the fumigating wharf are used, the fumigating barges then being moored and used as floating fumigating chambers only. Under this system the capacity of the fumigating plant is increased by 50 per cent. The plant at present provided in Bombay is capable of dealing with some 1,300 bales of cotton daily.

Though cumbersome, this method of handling American cotton for fumigation has several advantages, especially as imports are far from regular. The system is elastic and readily adaptable to consignments of varying size. Cotton is not landed until after fumigation and there is the minimum of handling of cotton before it is fumigated. It was at first intended to confine the importation of American cotton to the fair weather season and to prohibit importations entirely during the monsoon, but it was found possible by a slight modification of the scheme to avoid this interruption of trade. During the monsoon period fumigation is carried out in the Docks, utilising berths which in the fair weather are required for the coasting trade. To deal with the possibility of American cotton having to be discharged at a time when, owing to weather conditions, fumigation might be impossible, a quarantine shed is provided in the Docks.

The cost of fumigation [1] is appreciable and is paid by the importer. Fortunately, it has now been found possible to reduce these charges ; indeed it was one of the first objects of the experimental work described in the memoir to ascertain how fumigation could most economically be conducted. Experimental work progressed step by step with the arrangements for the introduction of fumigation on a commercial scale and the latter was started as soon as the necessary data were forthcoming, refinements being introduced as additional light was thrown on the subject. The memoir describes experimental methods adopted and should be of use to anyone who may be called upon to deal with the destruction of insect pests of similar type on a commercial scale.

B. C. BURT.

[1] For details see Appendix V. Of the present charge of Rs. 3-1-0 per bale, Rs. 2-1-0 is on account of handling charges, including the conveyance of the cotton to the special fumigation wharf.

SUMMARY.

The memoir describes experiments undertaken to ascertain the conditions under which hydrogen cyanide would be a satisfactory fumigant for American cotton bales, which, it has been feared, might be a vehicle for the introduction into India of the Mexican Boll-Weevil (*Anthonomus grandis*). Experiments were carried out on three scales, *viz.*, small-scale, one-bale scale, and full-scale. Most of the experiments were carried out on the small scale, using a glass vessel (actually a large desiccator) as a container for the material being fumigated (cotton, etc.). The hydrocyanic acid gas was generated direct in this glass vessel ; a method was worked out for sampling at intervals the atmosphere produced therein. The apparatus is described in detail and the possible sources of error fully discussed ; the conclusion is reached that the apparatus was quite satisfactory for the purpose desired. Various chemical difficulties were encountered ; among these was the effect of the presence of chloride as impurity in the cyanide used for the generation of HCN. Some results of analyses in this connection are given. Other interesting results obtained were that larger and more constant yields of HCN are produced when a little water is present in the cyanide-acid reaction ; and that concentrated sulphuric acid is a strong absorbent of HCN.

Experiments were carried out to determine first, what concentration of HCN and what duration of exposure are necessary in order to exterminate the weevils ; and secondly, whether the cotton or its jute covering may absorb and subsequently desorb HCN, and, if so, to what extent. In India the experiments were confined to a resistant weevil—the grain-weevil, *Sitophilus oryzae*—but it was subsequently arranged with the authorities in America to repeat the work there using the Mexican Boll-Weevil itself.

It is concluded from the experiments that to ensure the extermination of the grain weevils under Bombay conditions, it is sufficient to expose them for a period of 20 hours to a HCN-concentration of 150 parts HCN per 100,000 by volume (calculated as at normal temperature and pressure). The weevils were found to be much more susceptible to the influence of the HCN at higher than at lower temperatures, and it appears that a temperature of 86°F. is fairly critical, there being a marked difference in susceptibility on either side of this temperature.

From an examination of the experimental results for the Mexican boll-weevli, it appears that there is not a great difference in susceptibility between the grain-weevil and the boll-weevil and that the temperature has an important effect on the susceptibility of the boll-weevil also ; if anything, the boll-weevil is more sensitive than the grain-weevil, at any rate to exposures for a comparatively short time at high HCN-concentration. The conclusion is drawn that under Bombay conditions the boll-weevils would be exterminated by an exposure for 4 hours to a HCN-concentration of 450 parts HCN per 100,000 by volume or for 20 hours to

a HCN-concentration of 150 parts HCN per 100,000 by volume (calculated as at normal temperature and pressure). For most effective working on a practical scale. it is further concluded that the best procedure is to combine a short-period fumigation (6 hours) at a high concentration with a long-period fumigation (a further 12-14 hours) at a lower concentration, the minimum initial concentration for the second period being not less than 200 parts HCN per 100,000 by volume.

The conclusions drawn from the cotton absorption experiments are : (1) That cotton does absorb HCN, whether the cotton be loose or baled, dry or damp ; (2) that damp cotton is rather more absorbent than dry cotton, the difference in absorption for extremes of humidity being about 50 per cent. of the dry absorption ; (3) that within the limits of temperature 86°-104°F. the actual temperature has very little influence either on the rate or on the degree of absorption of HCN by cotton ; (4) that absorbed HCN is desorbed fairly rapidly and completely, and that there is no evidence of the occurrence of any irreversible chemical combination ; (5) that with water present in the cyanide-acid reaction the weight of sodium cyanide required for satisfactory fumigation is about 0·05 per cent. of the weight of the cotton, but that where leakage has to be contended with, as when using barges on a practical scale,—the weight of sodium cyanide required is about 0·07 per cent. of the weight of the cotton, or one pound weight of sodium cyanide for three bales of cotton. Subsequent experience on the practical scale has shown, however, that one pound weight of sodium cyanide is sufficient for the satisfactory fumigation of about five bales of cotton, when good barges are used and when the bales are both dry and also compressed to a high density ; (6) that fumigation with HCN can be satisfactorily carried out on a large scale in barges.

The conclusions drawn from the jute absorption experiments are : (1) That jute has about twice the absorptive power of cotton, and moreover absorbs the HCN at a more rapid rate ; (2) that the absorptive power of jute is only to a small extent dependent on its moisture content, being however slightly greater for damp jute than for dry ; (3) that the absorptive power of jute remains practically unchanged throughout the temperature range 86°-104°F.

The results of these experiments led the Government of India to issue in November, 1925, a Notification under the Destructive Insects and Pests Act, 1914, requiring all American cotton imported into India to be subjected to fumigation with HCN and confining such importation and fumigation to the port of Bombay. Experience which has since been accumulated in the application of this Notification to the fumigation of over 80,000 bales in barges, has amply confirmed the conclusions previously arrived at as to the absorptive capacity of cotton bales.

A. J. T.

D. L. S.

THE USE OF HYDROCYANIC ACID GAS FOR THE FUMIGATION OF AMERICAN COTTON ON IMPORT INTO INDIA.

(Experiments on its Lethal Power for the Mexican Boll-Weevil *Anthonomus grandis* and for the Grain-Weevil *Sitophilus oryzae*; on the Extent to which it is absorbed by Cotton and Jute respectively; and on a Practical Method for Satisfactory Fumigation on a Large Scale.)

BY

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(Received for publication on the 5th March 1927.)

I. Introduction: the Problem.

The ravages of the Cotton Boll-Weevil in America have excited grave fears that this pest might at some time or other be introduced into India. Should this happen, there can be but little doubt that it would cause great havoc among the cotton crops of this country also. The questions have therefore arisen: first, as to what are the most likely sources of introduction of the weevil, and, secondly, as to what steps might be taken as safeguards against the introduction of the pest from these sources.

Examination of the problem has led to the conclusion that the danger is most to be apprehended from weevils in American cotton bales. It is not regarded as feasible for live weevils to exist in the interior of a cotton bale, for it is most probable that no weevil would survive the action of the compress if it gained access to the cotton before the pressing; while it would not appear to be possible for a weevil to burrow its way into the interior of a pressed bale, even in the unlikely event of its attempting to do so. But real danger appears to threaten from weevils finding a convenient resting place in or below the gunny coverings of the bales. Thus, Dr. W. D. Hunter of the United States Department of Agriculture wrote in July 1922: "The longevity of the adult boll-weevil depends on seasonal conditions

In the summer it rarely lives as long as fifty days. In the cooler portions of the year it has been known in numerous cases to live as long as six months. Therefore as far as the time element is concerned, the establishment of the weevil in India by carriage on bales of American cotton would be a distinct possibility. The American cotton is wrapped in very coarse jute fibre. The covering gives many opportunities for the boll-weevil or other insects to be carried. Many thousands of the weevil are concentrated around the gins each season where they may easily make their way to the bales which are lying on platforms awaiting storage."

There are a number of other routes—more or less indirect—by means of which the boll-weevil might conceivably find its way to India. And although examination of such possibilities shows them to be very remote contingencies, against which the most stringent precautions might be taken in vain—as in the case of any other insect pest—their existence does make it impossible to guarantee that the boll-weevil can in any case be kept out of India for all time.

But while it may be impracticable to close every possible avenue by which the boll-weevil might reach India, there is nevertheless, as already indicated, every reason to suppose that the American cotton bales constitute by far the most likely source of infection. It is, therefore, concluded that if all such cotton bales are satisfactorily fumigated on arrival in India the likelihood of the introduction of the weevil is reduced to a minimum. The present paper is a description of experiments undertaken with a view to determining what constitutes "satisfactory fumigation". Most of these experiments were carried out on a small scale in the Laboratory. Seeing that the cost of the fumigation is a most important matter from the practical aspect, some experiments were also carried out to see whether satisfactory fumigation could be done in barges, the use of which appeared to have great advantages both from the point of view of cost and also of flexibility. There is a big gap, however between purely laboratory experiments and experiments with, say, 80 bales of cotton in a barge hold; moreover, it is impossible to ensure that a barge hold is really very gas-tight. It was nevertheless desirable to confirm the small scale Laboratory results on a larger scale, and so some further experiments were made on an intermediate scale, in which a single bale of American cotton was subjected to treatment.

(i) The Toxicity of Hydrogen Cyanide.

Before proceeding with the description of these experiments it is necessary to define their scope. According to Liston and Goré [1] previous work had shown that for animal life hydrocyanic acid gas (HCN)* was a deadly poison. although its

[1] W. G. Liston and S. N. Goré. The Fumigation of Ships with Liston's Cyanide Fumigator: *Journal of Hygiene*, Vol. XXI, No 3, May 18, 1923.

* For the sake of brevity, hydrocyanic acid gas (hydrogen cyanide) is henceforward referred to throughout as HCN.

potency varied according to the particular subject. They give the following lethal concentrations for different members of the animal kingdom :—

TABLE I.

Subject	Lethal concentration parts by volume per 100,000 of air	Duration of exposure necessary
Dog	8	30 minutes
Cat	12	,,
Rabbit	15	,,
Rat	20	,,
Monkey	25	,,
(Man)	(25)	,,

Various other interesting results on the toxicity of HCN are contained in recent scientific literature, a Bibliography of which forms Appendix I.

It was thought desirable, therefore, to try the effects of HCN on weevils also. Already HCN was used for the fumigation of imported cotton in the United States of America, where it had been found that such fumigation in no wise affected the spinning and other valuable practical qualities of the cotton. It was quickly discovered that HCN was not nearly so potent for weevils as for the mammals in the above list. This perhaps is not surprising in view of the fact that the breathing apparatus of the weevils is of the most rudimentary character, so that a considerable time must probably elapse before an external high concentration of HCN can produce a moderately high concentration inside the breathing apparatus of the weevils.

(ii) The Toxicity of Formaldehyde.

There is, of course, the possibility that some substance other than HCN might be more potent in its action on weevils. The choice of substances was limited, however, by the fact that it was proposed to use the substance for the fumigation of cotton bales; evidently, therefore, no substance which had any deleterious action on either cotton or jute could be used for the purpose. A few experiments were in fact tried with formaldehyde, generated by the action of 40 per cent. formalin on powdered potassium permanganate, but as the potency of the formaldehyde as a weevil-killing agent was found to be less than one-tenth that of HCN, the

experiments were discontinued. Moreover, there was considerab'e urgency in the solution of the problem and a thorough examination of all possible substances would have meant long delay in working out completely a satisfactory procedure for any one substance. Under these circumstances the experiments were restricted to the use of HCN.

(iii) Generation of Hydrogen Cyanide : Effect of Chloride as Impurity.

For the purpose of this work it was proposed on grounds of economy and of safety to generate the HCN from sodium or potassium cyanide and sulphuric acid, and not to use liquid HCN as is commonly done in America. As commercial cyanides usually contain a certain amount of chloride, the question arose as to what would be the effect of the presence of chloride. In Liston's paper[1] he quotes from " the very important monograph on fumigation with HCN prepared by the United States Agricultural Department, Bureau of Entomology, Bulletin No. 90, published in three parts in 1911 and written by R. S. Woglum and C. C. McDonnell. The usual method of generating the gas consists in adding solid lumps of cyanide to a 1 to 2 or a 1 to 3 solution of sulphuric acid in water.....McDonnell concludes from the experiments he records, ' that the presence of chlorides or nitrates in cyanides which liberate hydrochloric and nitric acid respectively, together with hydrocyanic acid, on treatment with sulphuric acid cause very marked decomposition of the hydrocyanic acid. The effect produced by hydrochloric acid is much more marked than that produced by nitric acid. In one case, over 92 per cent. of the hydrocyanide acid was decomposed and only a little over 7 per cent. evolved. This is a larger amount of sodium chloride than would ever be found in a commercial sample, but it shows the important bearing this impurity has upon the results. Practically, all commercial potassium and sodium cyanides contain sodium chloride in greater or less amount. Potassium cyanide is frequently sold as " 98-99 per cent. pure " which in reality is a mixture of potassium cyanide, sodium cyanide, and sodium chloride and on analysis may show even 100 per cent. expressed as potassium cyanide, yet there may be several per cent. of sodium chloride present. For fumigation work an analysis of a cyanide is of little value unless the chlorin content is also determined.' "

Tests on this point, however, did not confirm McDonnell's results. Even the purest cyanide which could be obtained contained a small amount of chloride ; evolution of HCN was in general about 70 to 80 per cent. of the theoretical value, but bore no relation to the content of chloride. Some experiments were then made with synthetic control mixtures of cyanide and chloride in the proportion 60 : 40 and in each case the quantity of HCN evolved was almost exactly proportioned to

[1] W. G. Liston: The use of Hydrocyanic Acid Gas for Fumigation: *Indian Journal of Medical Research*, Vol. VII, April 1920, 783.

the content of cyanide. These results are detailed in Appendix II. From other results which are described later (page 95) it appears that the low values sometimes obtained by McDonnell are to be ascribed rather to the method of generation than to the chloride content of the cyanide. The lumps of cyanide added will almost certainly not have been of a uniform size, and different concentrations of acid were employed on different occasions. As will be shown hereafter, these conditions were almost ideal for the production of varying yields of HCN in different experiments.

Bearing in mind that the evolved gas has to be used for the fumigation of cotton however, it is important to ensure that there shall be the minimum amount possible of hydrochloric acid gas produced. For this reason, the cyanide used in actual fumigation on a practical scale is of the highest degree of purity obtainable.

(iv) The problem involved.

It has already been stated that the chief object of these experiments was to ascertain what constitutes "satisfactory fumigation." In the main, this resolves itself into determining first, what concentration of HCN and what duration of exposure are necessary in order to exterminate the weevils; and secondly, whether the cotton or its jute covering can absorb and subsequently give off HCN, and if so, to what extent. As regards the first point, some danger would obviously have attended the introduction of the boll-weevil into India even for these experimental purposes, and the experiments were therefore chiefly confined to the grain weevil, *Sitophilus oryzae* which in a few preliminary experiments was found to be much the most resistant of the various indigenous weevils experimented with, *viz: Myllocerus*, *Odoiporus*, *Polytus* and *Sitophilus oryzae*. As regards the second point, there were two considerations involved,—a minor one concerning the probable consumption and cost of chemicals on a practical scale, and the consequent feasibility of using the method proposed; the major and much more important consideration was that, as HCN is highly poisonous, it would be necessary to provide ample safeguards for the men who would have to handle the cotton after fumigation. In order to achieve the objects in view it was therefore necessary to find answers to the following questions:—

1. Under what simultaneous conditions of concentration of HCN, duration of exposure and temperature, can the grain weevils be killed with certainty?
2. To what extent, if any, is HCN absorbed by cotton and jute respectively?
3. To what extent is the absorption, if any, of HCN by cotton and jute respectively dependent on any or all of the conditions of concentration, time of exposure, humidity, and temperature?
4. To what extent, if any, do cotton and jute respectively give off HCN after being removed from an atmosphere containing this gas?

For convenience of treatment, the investigations carried out to answer these questions are considered under the following divisions :—

II. Experimental Apparatus and Methods : Sources of error.
III. Blank Experiments : Chemical difficulties.
IV. Experiments with the Grain-Weevil.
V. Experiments with the Boll-Weevil.
VI. Experiments with Cotton and Cotton Bales.
VII. Experiments with Jute.
VIII. General Discussion of the Results : Practical Considerations.
IX. Conclusions.

The experiments on the three different scales were carried out more or less simultaneously, but the description of them for any one division will be simpler to follow if given, not in the chronological order, but in the order of increasing scale, the small scale (desiccator) experiments being dealt with first, then the intermediate scale (one-bale) experiments, and lastly the full-scale experiment.

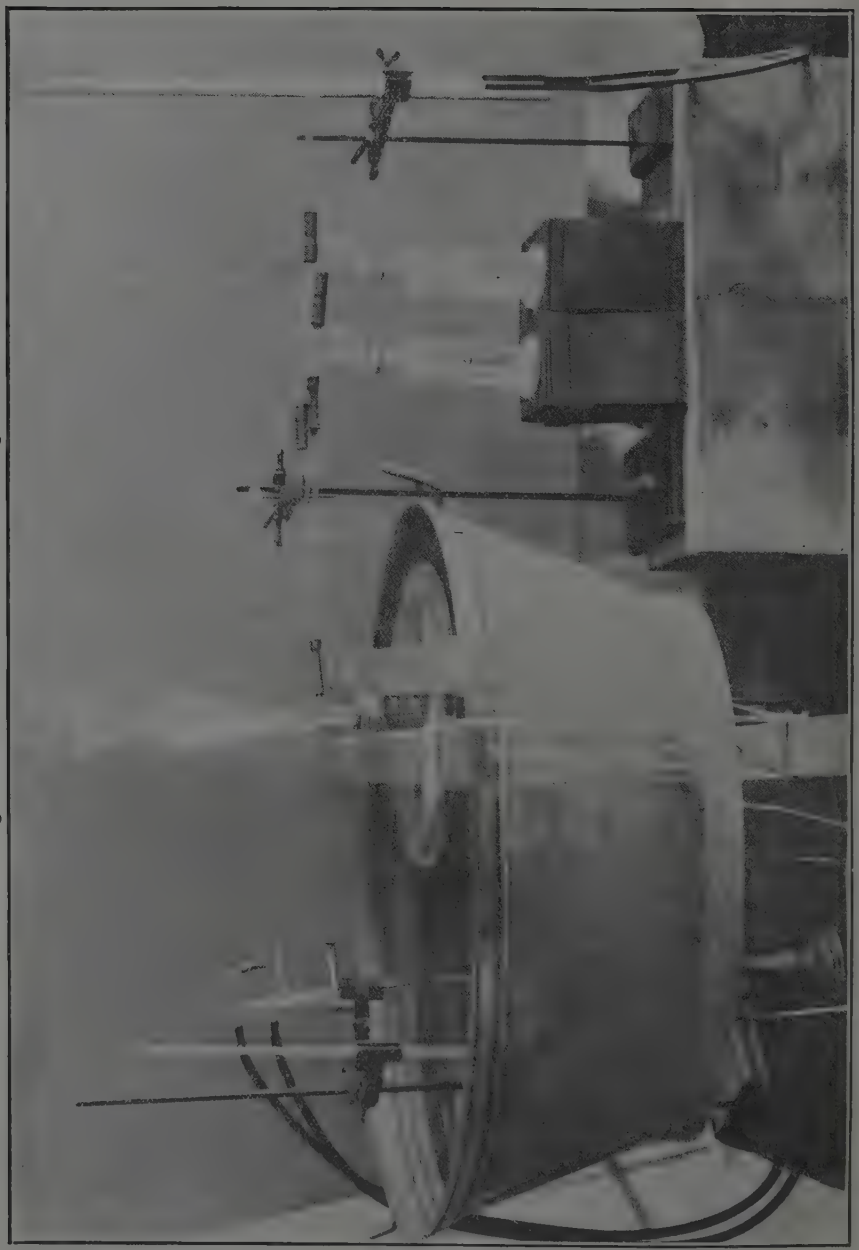
II. Experimental Apparatus and Methods : Sources of Error.

1. Small-Scale (Desiccator) Apparatus.

(*a*) *General.*

For the small scale work it was necessary to design a piece of apparatus from which samples of the atmosphere could be taken from time to time as desired. The first method tried was to generate HCN in a large desiccator of which the pressure was taken by a mercury manometer, and to exhaust the desiccator to a measured partial vacuum, the drawn-off air being passed through absorbent solutions in Drechsel bottles. This method failed, however, as it was not found possible to render the apparatus sufficiently gas-tight to maintain the partial vacuum for any long period ; it was found that the Drechsel bottles were not gas-tight under these conditions, although other parts of the apparatus were effectually sealed. As a consequence it was not possible to measure the amount of air withdrawn from the desiccator by the reading of the manometer. The same difficulty would have occurred if an aspirator had been attached to the end of the washing-bottles for the purpose of reducing the pressure in the desiccator ; the volume of the water run out of the aspirator would, of course, have measured the volume of the air which had leaked into the apparatus as well as the volume of air withdrawn from the desiccator. This trouble of leakage might have been overcome but even so the aspirator method would not have been so good as that actually adopted (as described below), because successive determinations in a single experiment would have involved rarefy-

PLATE XXII.



Small-Scale Fumigation Apparatus.

ing or diluting the desiccator atmosphere, which could not therefore have been maintained at even an approximately constant composition (mass of HCN per c.c.) throughout the experiment.

Another method was therefore sought in which the required sample of air was driven out positively. In connection with the large-scale experiments, which were carried out in a barge, it had been feared that some water might leak into the barge and, lying in the bottom of the barge, might dissolve a great deal of the HCN generated. Some experiments had therefore been undertaken on the absorption of HCN by various liquids with a view to finding if possible a liquid which could be used to seal off any such water in the barge from the HCN-containing atmosphere. Such a liquid, besides being lighter than and non-miscible with water, had also of course to be non-absorptive of HCN. Pure liquid paraffin had been found satisfactory in this respect. Pure liquid paraffin was accordingly tried as a displacing liquid to drive samples of the air out of the desiccator and through the gas-washing bottles. This method proved quite successful. With the simple piece of apparatus which was devised, experiments could be carried out accurately and expeditiously, with the maintenance at the same time of a more complete control over the experiment than is possible in large-scale experiments. Its use overcame the greatest difficulty encountered in the large-scale experiments, *viz.*:—that of making the apparatus gas-tight.

Briefly, the method adopted consists of generating HCN in a large desiccator containing the weevils, etc., and of taking samples of the gas at subsequent intervals by driving out a known volume of the gas through washing-bottles containing a solution which absorbs the HCN present. The gas is driven out of the desiccator by replacing it by an equal volume of pure liquid paraffin. It may here be observed that the first determination of HCN-concentration was invariably made about a quarter of an hour after the generation of the HCN ; for the remainder of the experiment the displacing liquid covered the bottom of the desiccator, presenting a large absorptive surface to the atmosphere therein. And as a single experiment usually extended over many hours, during which a number of determinations of HCN-concentration were made, it was very important that the displacing liquid used should be almost completely non-absorptive towards HCN. It was actually found that other similar liquids—kerosene, and liquid paraffin which was not of the highest degree of purity—did in fact absorb HCN very slightly, but to a sufficient extent to render them useless as displacing liquids.

(*b*) *Description of the Small-Scale Apparatus.*

Reference to Fig. 1 and Plate XXII will make clear the *modus operandi* of the test. F is a porcelain plate ; it rests on the shoulder of the desiccator G and contains 6 holes on which a number of crucibles E may be placed. In each crucible E is placed a given charge of sodium cyanide, usually either 0·05 or 0 10 gram. HCN is generated

by running a few drops of concentrated * sulphuric acid through the tap B of the funnel A, whose stem passes through the rubber cork C to the interior of the desiccator G. The bent tube D is attached by rubber tubing to the stem of the funnel A inside the desiccator. The connection of rubber tubing is placed as near to the cork C as possible. The tube D is bent in such a way that by turning the funnel A the lower end of D swings round for the purpose of delivering liquid above any of the 6 holes in the plate F ; in any one experiment not more than 5 of these holes would be occupied by the crucibles, at least one hole being kept clear for the displacing liquid to pour through.

A delivery tube T leads from the desiccator through cork C to a three-way tap H, by means of which the interior of the desiccator may be put into communication either with two Drechsel washing-bottles K and L, or with a second three-way tap M communicating either with the external air or with a water-manometer N. These connections with the external air and with the manometer are necessary in order to eliminate possible errors due to changes in the temperature or pressure during the course of an experiment.

The following are the dimensions of the different parts of the apparatus :—

Desiccator G : Inside diameter 10 inches.
Capacity 10·7 litres.

Crucible : Diameter at top 1·1 inch.
Depth 0·8 inch.
Capacity 6 c.c.

Drechsel bottles : Capacity 8 oz. each.

NOTE.—A volume of 100 c.c. of solution in a Drechsel bottle gives a pressure-head of 2 inches.

(c) *Possible Sources of error.*

1. *Volume of HCN generated.* With a charge of 0·10 gram of dry sodium cyanide, the volume of HCN produced in Bombay is about 50 c.c., so that with such a charge the pressure inside the desiccator rises after the generation of HCN by about one two-hundredth, even when the heat generated by the reaction has been dissipated. This error was avoided by equalizing the internal and external pressures of the desiccator before making the first determination of HCN-concentration, as described hereafter (page 81). If this had not been done and a volume of 250 c.c. of displacing liquid had been used for the first determination of HCN-concentration, the volume of the emergent gas would have actually been about 300 c.c. instead of 250 c.c.

2. *Temperature and pressure changes.* Owing to the long period over which a single experiment might extend, in the absence of control of the temperature and

* Compare page 94 *et seq.*

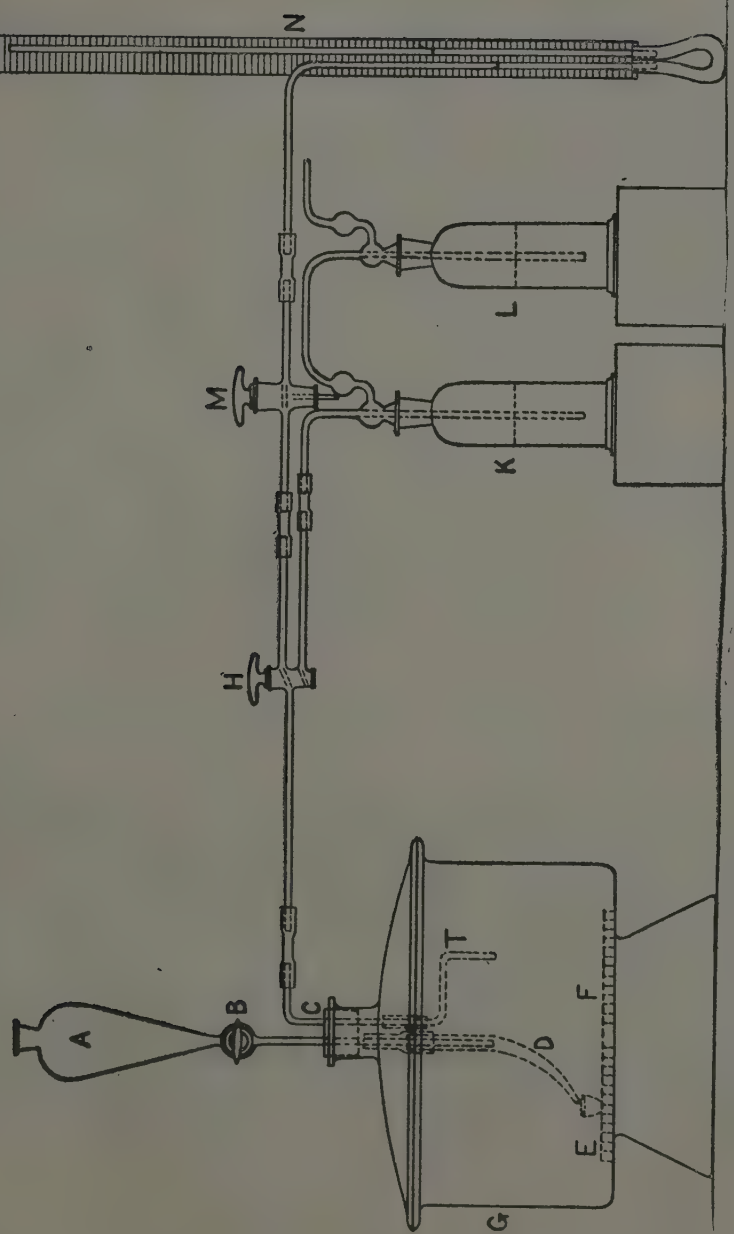


Fig. 1. Small Scale Fumigation Apparatus.

pressure different determinations might be made at considerably different temperatures and pressures. In this respect it is very fortunate that normally the temperature and pressure changes in Bombay take place within very narrow limits over fairly considerable periods of time. The volume of the desiccator itself may be taken as constant, for the effects produced by changes in the temperature and pressure on the volume of the desiccator are negligibly small compared with their effects on the enclosed air. A simple calculation shows that, with constant volume, for every 1°F. rise or fall in temperature there is a corresponding increase or decrease of approximately one five-hundredth of the internal pressure; this amounts to about 0·06 inch mercury and is the equivalent of a volume of about 20 c.c. of the air within the desiccator. If therefore between two determinations the external temperature had fallen as much as 10°F., and the internal temperature had adjusted itself to the external temperature when the second determination was made, there would have been a partial vacuum inside the desiccator and 200 c.c. of the 250 c.c. displacing liquid would have been used in compensating for this partial vacuum, and instead of 250 c.c. only 50 c.c. of air would have been driven out. With a rise in temperature of 10°F. between two determinations the volume of air driven out would have been 450 c.c. instead of the 250 c.c. of the displacing liquid. Similar disturbances would have resulted if between any two determinations of concentration there had been a rise or fall respectively of 0·6 inch mercury in the external pressure. It will be observed that whether the change in the external physical conditions is one of temperature or pressure it finds expression in a change of pressure within the desiccator; to eliminate changes due to either, therefore, all that was necessary was to provide a means whereby the internal and external pressures could be equalized just before a determination was made of the HCN-concentration.

3. *Secondary sources of error.* There remain three other difficulties of a secondary nature. The first is presented by a fall in the external temperature or a rise in the external pressure between successive determinations of HCN-concentration. This would show itself on the manometer as a partial vacuum in the desiccator. To relieve this vacuum it would be necessary to admit air; this admitted air might cause trouble in two ways:—(1) It would of course dilute the air in the desiccator. The extent of dilution is readily calculable from the pressure readings of the manometer, and in all normal cases its effect would be negligible. (2) As the sample of air is taken immediately after the equalization of pressures, the air within the desiccator would probably not be of uniform composition so that the air driven out might not be a true sample. The possible error from this source is comparatively large; from the reading of the manometer its higher limit could be calculated, and this would, of course, be equal to the error involved if no equalization of pressures were made. On this account, if any large pressure difference were encountered, the best method to adopt would be to make the equalization of pressures a number of times at short intervals *between* each pair of the determinations of HCN-concen-

tration; in this way the difference between the internal and external pressures would never be very great. Alternatively, the equalization of pressures could be effected by running liquid paraffin into the desiccator through the funnel A, using the manometer to measure the rate of equalization. So far as the partial vacuum was due to temperature changes, it could be avoided by keeping the desiccator in a constant-temperature bath. The first method could not conveniently be used in experiments of long duration, as it was during the night, of course, that falls of temperature were most commonly experienced. The third method was actually used in absorption experiments with cotton and jute, as will be explained later. The only objection to the second method is that the use of liquid paraffin for equalizing the pressures reduces the volume available for making determinations of concentration. This method was not used at the Technological Laboratory because, in general, it was rising and not falling temperatures which were experienced, due to each experiment being started fairly early in the morning. The occasional falls in temperature which were experienced were demonstrably not serious owing to their small magnitude.

The second difficulty to which reference was made above is that the displacing liquid might be at a slightly different temperature from that of the desiccator. There would, of course, at once be a tendency towards temperature-equilibrium between the liquid and the desiccator: at the same time, there would be a tendency towards a temperature-equilibrium between the whole system and the external air. These changes in temperature would be accompanied by volume changes which would be negligible for the liquid and the desiccator but not necessarily so for the contained air. The temperature changes in the Technological Laboratory were, however, over such a small range and took place so slowly that no great error would be introduced in this manner, as was confirmed by some subsequent experiments on the point, when the temperatures of the liquid paraffin were found not to differ by more than 0·5°F. from the temperatures in the desiccator.

The third difficulty might arise from the comparatively rapid adjustment of pressures on equalizing the internal and external pressures. If the internal pressure had risen relatively to the external pressure between two determinations of HCN-concentration, then on equalizing pressures there would have occurred expansion of the air inside the desiccator accompanied by some cooling, assuming the expansion to have been so rapid as to have been approximately adiabatic. During the running-in of the displacing liquid, therefore, the temperature of the air in the desiccator would have gradually risen and a larger volume of air than that of the displacing liquid would have been driven out. In point of fact, owing to the very small bores of the tubes and of the three-way taps, the expansion of the air within the desiccator is far from being purely adiabatic; moreover, about 2 minutes may be taken up in reaching a position of final equilibrium between the internal and external pressures; and lastly, even if the expansion were purely adiabatic, the

adiabatic effect could not be more than 29 per cent. of the expansion which would result from the original temperature and pressure changes.

To determine the magnitude of any such adiabatic effect, some observations were actually made with the desiccator, using excess internal pressures of the order of the maximum of those occurring in the fumigation experiments. First, the pressure inside the desiccator was brought to the desired excess above the external pressure: next, three-way tap M was turned so as to put the desiccator into communication with the external air ("air-communication") for a given period. Tap M was then turned so that communication was resumed between the desiccator and the manometer ("manometer-communication"); this caused the water in the manometer to oscillate for about 6 seconds before it settled down. The subsequent movement of the water levels in the manometer showed that the internal pressure gradually rose as thermal adjustment set in. In all cases the water came practically to its final equilibrium level within half a minute of the resumption of manometer-communication. With the very short air-communication of 1 second (approx.) the equilibrium position after manometer-communication was attained within 10 seconds. With air-communications lasting 5 or 15 seconds nearly half a minute was required for equilibrium after manometer-communication; for the longer air-communication of 30 seconds equilibrium was again attained in about 10 seconds after manometer-communication. From these results it is clear that thermal adjustment is complete in about three-quarters of a minute after the beginning of the period of air-communication.

The curious differences between the times needed for thermal adjustment after manometer-communication for varying periods of air-communication may be traced to two distinct factors being involved, the first being the period of time necessary for the pressure-equilibrium to be established, and the second being the period of time necessary for the temperature-equilibrium to be established. As shown below, about half a minute is required to release the pressure within the desiccator owing to the small bores of the three-way taps, etc. If the equalization of pressures occurred under purely adiabatic conditions and the subsequent thermal expansion took place entirely after manometer-communication, the fall of pressure within the desiccator experienced by the time temperature-equilibrium had been re-established should be 71 per cent. of the initial excess pressure. Values actually obtained for different periods of air-communication were very different from this, *viz.*:—

Period of air-communication (seconds)	Fall of pressure (per cent. of initial excess pressure)
1	18
5	47
15	83
30	94

From these experiments it is clear that air-communication for rather more than half a minute is needed for the equalization of pressures, and that the thermal adjustment occurs in about three-quarters of a minute after the beginning of the period of air-communication. These results afford an explanation of the various times already referred to as being necessary for thermal adjustment after manometer-communication. In the 1 second air-communication experiments, only a fraction of the air within the desiccator had time to escape, so that the cooling effect was small and the thermal adjustment was consequently comparatively rapid. In the 5 seconds and 15 seconds air-communication experiments, the expansion was fairly considerable, with a fairly large cooling effect, so that nearly half a minute was necessary for thermal adjustment after manometer-communication. In the 30 seconds air-communication experiments, pressure-equilibrium was practically established and the greater part of the thermal adjustment must have taken place during the air-communication itself and before the manometer-communication was made. Thus the short periods required for establishment of equilibrium after manometer-communication in the 1 second and in the 30 seconds experiments are satisfactorily explained, although they arise from different causes.

In view of these results it will be seen that the procedure adopted to eliminate the various possible errors did in fact avoid this adiabatic error as well as the other errors to which attention has been drawn. This procedure will now be described.

(*d*) *Description of an Experiment in the Desiccator Apparatus.*

The charge of powdered sodium cyanide—0·10 gram—is spread evenly over the bottom of the crucible E and the latter set in position in the desiccator. In each of the washing-bottles K and L is placed 100 c.c. of the absorbing solution ($\frac{N}{5}$ caustic soda, 100 c.c. containing 0·1 gram potassium iodide). The lid of the desiccator is then placed in position, the rim being well covered with vaseline so as to make the joint with the body of the desiccator gas-tight when the lid is pressed down. The delivery tube T is then connected with the tube attached to the three-way tap H. The rubber cork C and the exterior rubber connections are well covered with a gas-tight mixture made by melting together 30 parts of beeswax and 40 parts of vaseline, and then adding to the mixture 15 parts of powdered resin and stirring. 0·3 c.c. of concentrated sulphuric acid[1] is placed in the funnel A. This quantity of acid is in large excess for the charge of cyanide, first because some of the acid is inevitably left on the internal wall of the stem of the funnel A, and secondly because it is desired to ensure that, if possible, no undecomposed cyanide shall be left in the crucible.

Tap H is put in communication with tap M, which is itself put into communication with the air in order to equalize the internal and external pressures; tap H is

[1] Compare, however, page 96.

then closed ; next, tap B is turned and the sulphuric acid allowed to run into the crucible E fairly quickly in successive drops. A violent action at once ensues, small clouds of vapour being evolved, but with the last drop or two no action is apparent ; after a short time taps H and M are opened for air-communication and pressure-equalization. Tap H is then closed once more and a small quantity (2 c.c.) of liquid paraffin is run into the crucible E, where it floats upon the liquid already present and thus seals it off from the atmosphere within the desiccator. The funnel A with its stem is then turned round so that the bottom of tube D is directly above the unoccupied hole in plate F. Next, the wax mixture on the cork C is partially melted by pressing on to it a heated rod ; the wax on resolidifying effectually seals this part of the apparatus. A quarter of an hour is invariably allowed to elapse before any determination of the concentration of the gas is made ; this is to allow the atmosphere inside the desiccator to become of practically uniform composition by the process of diffusion. That this period of time is sufficient for the purpose is indicated by the fact that in blank experiments no material difference normally occurred between the first and subsequent determinations of the HCN-concentration of the atmosphere of the desiccator.

When any estimation is to be made of the composition of the desiccator atmosphere, the desiccator is put into communication with the manometer N by taps H and M. If the manometer shows the existence of any difference of pressure between the external atmosphere and that inside the desiccator, tap M is turned so as to put first the manometer and then the desiccator in communication with the external air. After a few seconds tap M is turned so as again to put the desiccator in communication with the manometer N. If after one minute the reading of the manometer shows that the pressure inside the desiccator is equal to atmospheric pressure, the experiment can be proceeded with ; if, as is usually the case, equilibrium is not attained at the first attempt, tap M is again turned so as to put first the manometer and then the desiccator in communication with the external air, after which manometer-communication is re-established, and so on, the process being repeated until the reading of the manometer N shows that the pressure inside the desiccator G is the same as that of the external air. When this has been accomplished (the whole process is complete in two or three minutes) the tap M is closed and tap H is put into communication with the Drechsel washing-bottles K and L. A measured volume of pure liquid paraffin is now run into the desiccator through the funnel A. This drives out of the desiccator an equal volume of the air inside, which is thereby caused to bubble through the solutions in the washing-bottles K and L. A volume of 500 c.c. of liquid paraffin was generally used for each determination in the earlier experiments, but in later experiments only half of this quantity, *viz.*, 250 c.c. was most frequently used.

A difficulty arises towards the end of each determination because the atmosphere in the desiccator is obviously subjected to an excess pressure equal to the sum

of the heads of the solutions in washing-bottles K and L. There are various means by which this difficulty might be overcome. The one actually adopted is gradually to lower the bottles away from their delivery tubes so that the head of liquid is gradually reduced to zero. First the bottle L is slowly lowered so that the rate of bubbling through the solution in bottle K remains approximately the same as during the previous part of the determination (1 to 2 bubbles per second). The bottle L is then placed on one side and the bottle K slowly lowered in its turn. The chief objection which can be raised to this process is that the reduction in the head of liquid through which the driven-out gas has to pass gives rise to the possibility that the last few bubbles may not pass through sufficient liquid to have their HCN removed. It is, however, quite easy to show that, providing due care is taken and the rate of bubbling always kept slow, the possible error arising from this source is negligible.

The solution in bottle K is now titrated against silver nitrate solution, of strength 0·569 gram $AgNO_3$ per 1,000 c.c. solution. This strength is only about one-third centinormal strength and considerable care is necessary in the determination of the end-point of the titration. The method actually employed is to cause a beam of light to pass through the flask containing the solution being titrated, which is viewed against a black-paper background. The appearance of a faint permanent opalescence indicates the end of the reaction. If x denotes the number of c.c. of the silver nitrate solution used in the titration, and if 500 c.c. of liquid paraffin have been used for the estimation, *i.e.*, if 500 c.c. of air have been passed through the solution in bottle K,—then $(x \times 30)$ is the number of parts of HCN by volume per 100,000 parts of the atmosphere within the desiccator, at normal temperature and pressure. If 250 c.c. of liquid paraffin have been used for the estimation, then the number of parts of HCN by volume per 100,000 is given by $(x \times 60)$.

In any estimation the burette reading of silver nitrate solution is always observed to the nearest 0·05 c.c. If we assume the reading to be accurate to 0·1 c.c. only, it follows that the determination of HCN-concentration can only be accurate to 3 or 6 parts per 100,000 according as the volume of displacing liquid used is 500 c.c. or 250 c.c. respectively. Throughout this memoir all the values for HCN-concentration in parts per 100,000 by volume are given as at normal temperature and pressure, no correction being made for the temperature or pressure actually prevailing. It follows that these values are strictly proportional in each case to the mass of HCN per unit volume. And seeing that it is the mass of HCN per unit volume which presumably determines the lethal power of the gas, no real advantage would accrue from making the temperature-correction which would be necessary for each estimation. It may be added that as the temperature-correction is about 0·2 per cent. for every 1°F., the actual HCN-concentrations by volume at the temperatures prevailing in these experiments would be about 10 per cent. greater than at normal temperature; but the differences in temperature for different experiments were relatively small, so that direct comparisons of the HCN-concentrations could be

made legitimately. The same is true as regards the pressures experienced during different experiments.

The Drechsel washing-bottle L functions as a guard. Its contents are, however, titrated similarly to those of bottle K, but should give a permanent opalescence immediately the silver nitrate solution is added. If this is not the case, the reading obtained with the solution from bottle L must of course be added to that obtained with the solution from bottle K before the calculation is made of the HCN-concentration.

The material being fumigated was suitably arranged on the shoulder of the desiccator as nearly as possible symmetrically with regard to the crucible containing the charge of sodium cyanide. For example, when weevils were being experimented with, 3 small tins were arranged at the corners of a equilateral triangle and as nearly as possible symmetrically situated with regard to the crucible. Each tin had a diameter of 2 inches and was 0·6 inch deep; its lid was 0·4 inch deep and had a top of fine copper gauze having 60 wires to the inch. In any experiment 20 weevils were, if available, placed in each tin.

2. One Bale-Scale Experiments.

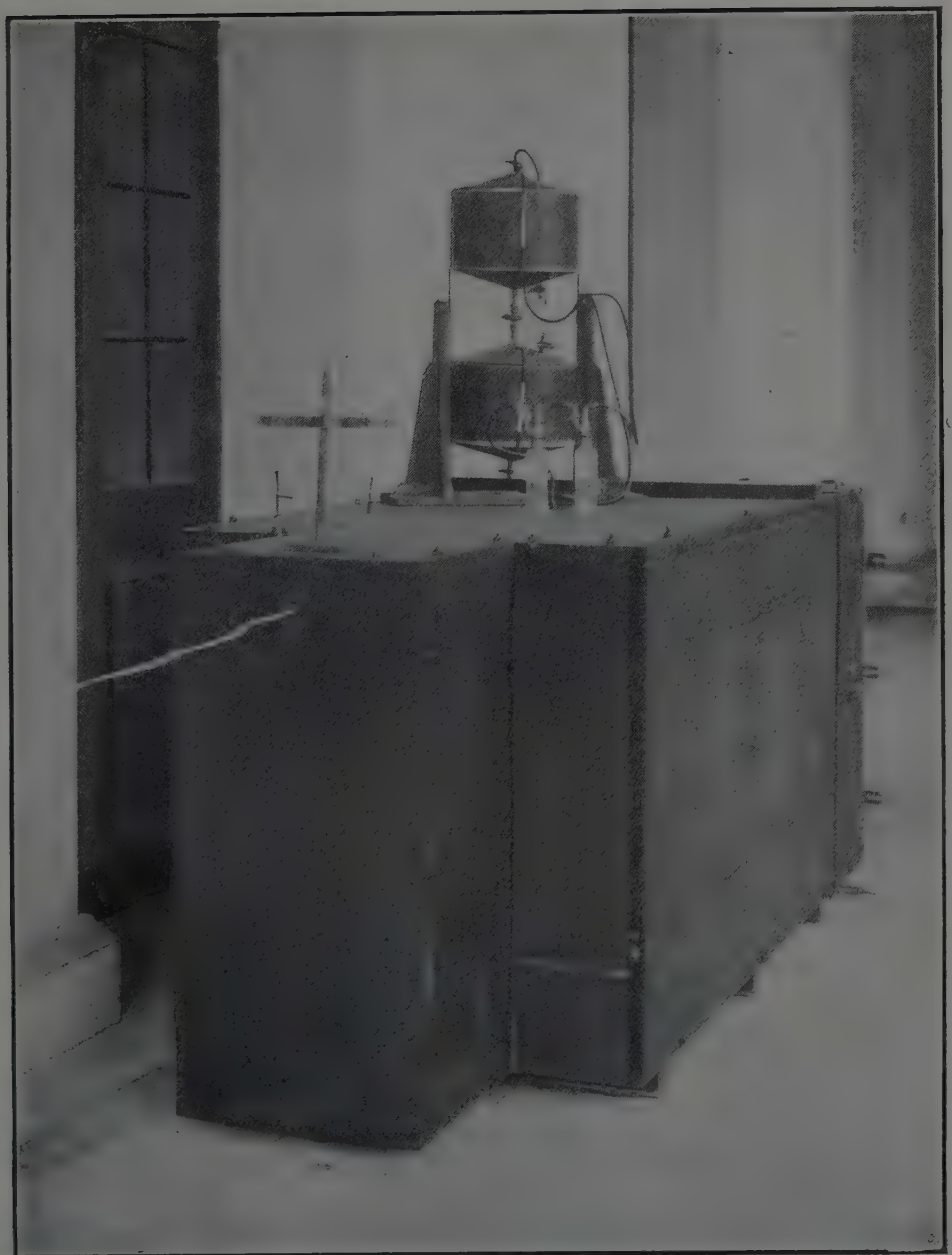
These experiments were first of all carried out in a large wooden chamber, and afterwards in a steel cylinder.

(*a*) *Wooden Chamber Experiments.*

The wooden chamber was made out of $1\frac{1}{2}$ inch teak: the internal dimensions were 5 ft. long × 3 ft. high × 3 ft. wide, giving a total capacity of 45 cubic feet; at one end, however, was a small additional compartment, 1 ft. 4 ins. deep × 1 ft. 4 ins. wide, extending the full height of the box. (Fig. 2 and Plate XXIII.) The total capacity of the wooden chamber was thus increased to 50·3 cubic feet. At the opposite end to this extension was fitted a door, which was made to close on to strips of felt fitted to the chamber, with a view to preserving the air-tightness as far as possible.

The extension was for the purpose of accommodating a tray E in which solutions of sodium cyanide and sulphuric acid could be made to interact: two glass tubings D, D′ led to the tray direct from the outside of the top of the extension, the respective solutions being poured into funnels A, A′ situated outside the chamber and attached to these glass tubings by rubber tubings B, B′ on which were screw clips C. C′ for controlling the rate of flow of the solutions. A small fan F was also placed in the extension for the purpose of aiding the circulation of gas.

The arrangement for sampling and testing the atmosphere within the chamber was similar to that used in the Liston's Cyanide Fumigator, described on page 89,



Wooden Chamber for Fumigation Experiments.

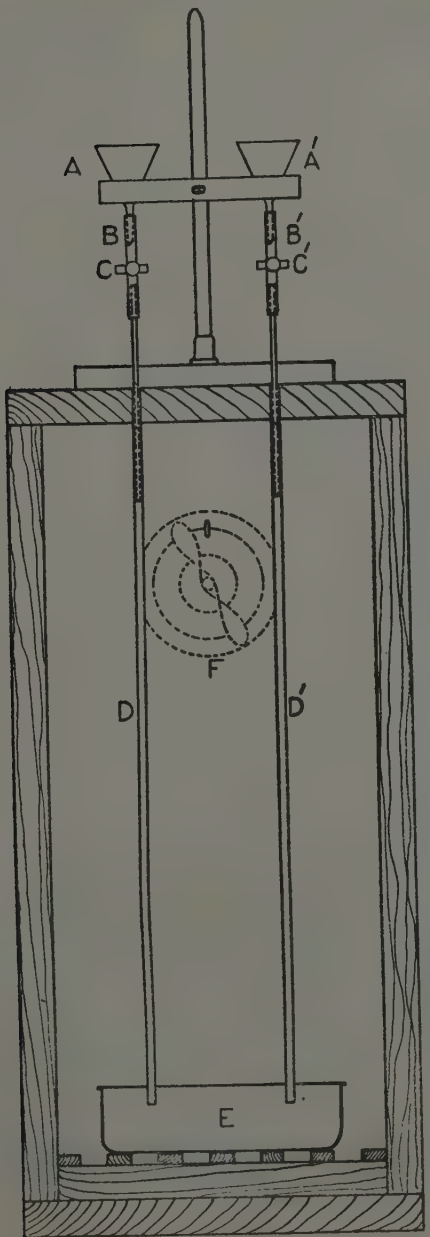


Fig. 2. Section of Extension of Wooden Chamber.

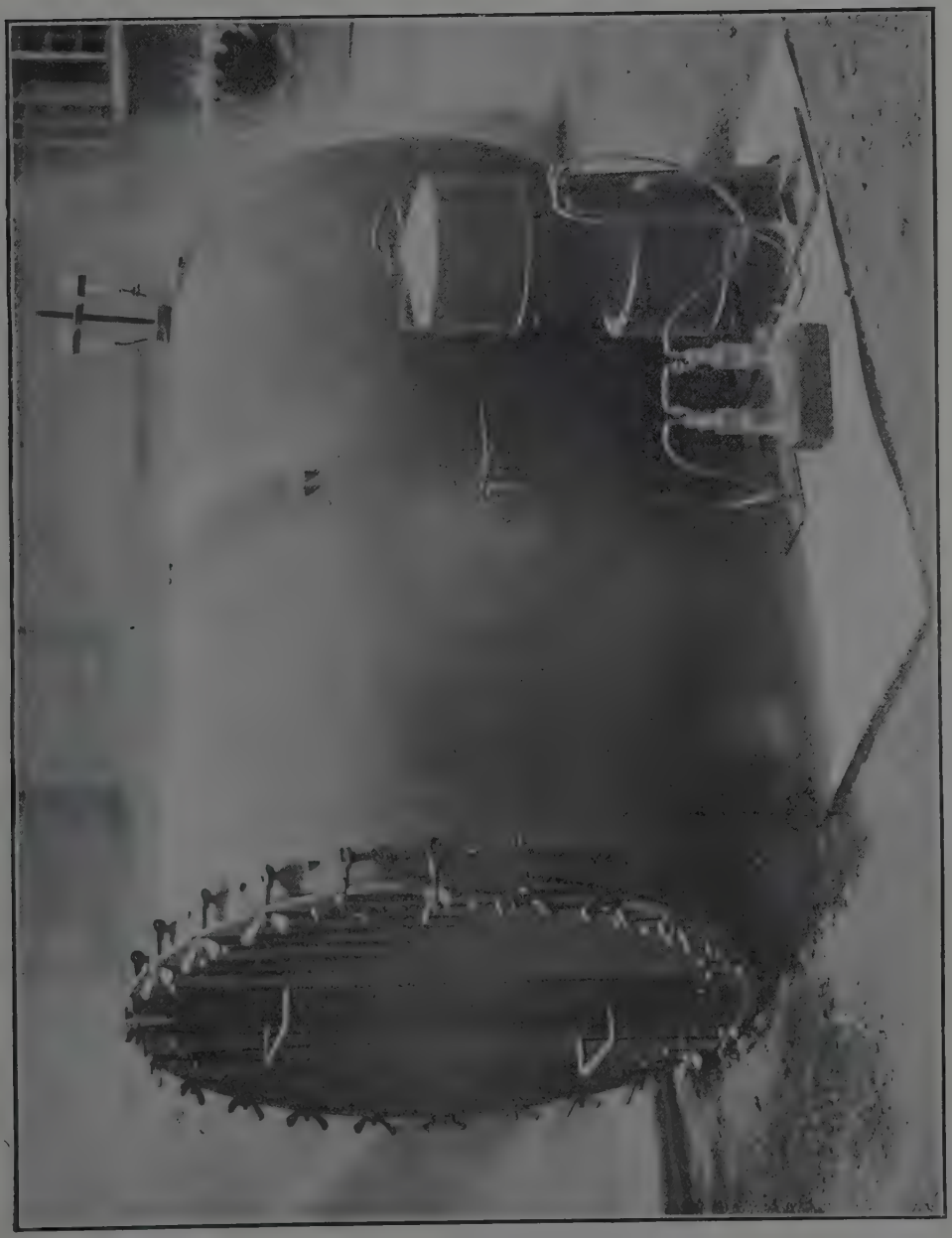
and is illustrated in Fig. 3 (also Plates XXIII and XXIV). It consists essentially of two copper vessels A, A′, each having a capacity of one half of a cubic foot, stayed one above the other and connected in series by a tube in which is a cock B ; a hinged clip J holds the two vessels in position on a wooden frame. The vessels are fitted with cocks F, F′ and G, G′, and by means of rubber tubing C, C′ are connected, through a T-piece D and two Drechsel gas washing bottles E, E′, with the interior of the wooden chamber. Each washing bottle contains the alkaline solution to absorb HCN ($\frac{N}{5}$ caustic soda, 100 c.c. containing 0·1 gram potassium iodide). For a determination of the HCN-concentration in the chamber, cocks F′, B, G are closed, the upper copper vessel A is filled with water through tap F and the connections made, tap F′ being left open. Cocks G′ and B are then opened, thus allowing the water to flow from the upper vessel to the lower ; this causes an equal volume of air to be drawn from the wooden chamber through the washing-bottles. When the whole of the water has run into vessel A′, the washing-bottles are disconnected, and the solutions in them titrated with standard silver nitrate solution (10·828 grams $AgNO_3$ per 1,000 c.c. solution). If x c.c. of this solution are used in the titration then $(x \times 20)$ represents the number of parts of HCN by volume per 100,000 parts of the atmosphere within the wooden chamber as at normal temperature and pressure. For the next determination all taps and cocks are closed, the rubber tubing disconnected from taps F, F′, and the positions of the copper vessels reversed by revolving the apparatus on pins H, H′ ; thus the lower vessel containing the water run in from the last determination now becomes the upper one, and *vice versa* ; fresh solutions are placed in the washing-bottles, the connections of the rubber tubings are again made and all is ready for a further determination.

Experiments were carried out in this chamber to determine the lethal concentration of HCN necessary for *Sitophilus oryzae* and the extent to which a cotton bale absorbed HCN. The chamber had to be extended in length by one foot at a later date in order to accommodate a bale of cotton. Its internal volume was thus increased to 59·3 cubic feet.

(*b*) *Steel Chamber Experiments.*

The wooden chamber proved unsatisfactory after a time (page 129) and a new chamber was therefore obtained of a cylindrical shape, made from quarter-inch steel sheets welded together, and having for one end a steel sheet door which could be securely clamped in position (Fig. 4 and Plate XXIV).

The cylinder was 6 feet long and 3 feet 9 inches in diameter, having a capacity of 66 cubic feet. The arrangements for generating the HCN and sampling and testing the atmosphere inside the tank were similar to those used in the case of the wooden chamber. A slight modification was made as regards the glass tubings D, D′, through which the interacting solutions were added ; these tubings were bent near their lower ends and then fixed in a cork G so that the issuing solutions should impinge on one another, and thus be well mixed.



Steel Chamber for Fumigation Experiments.

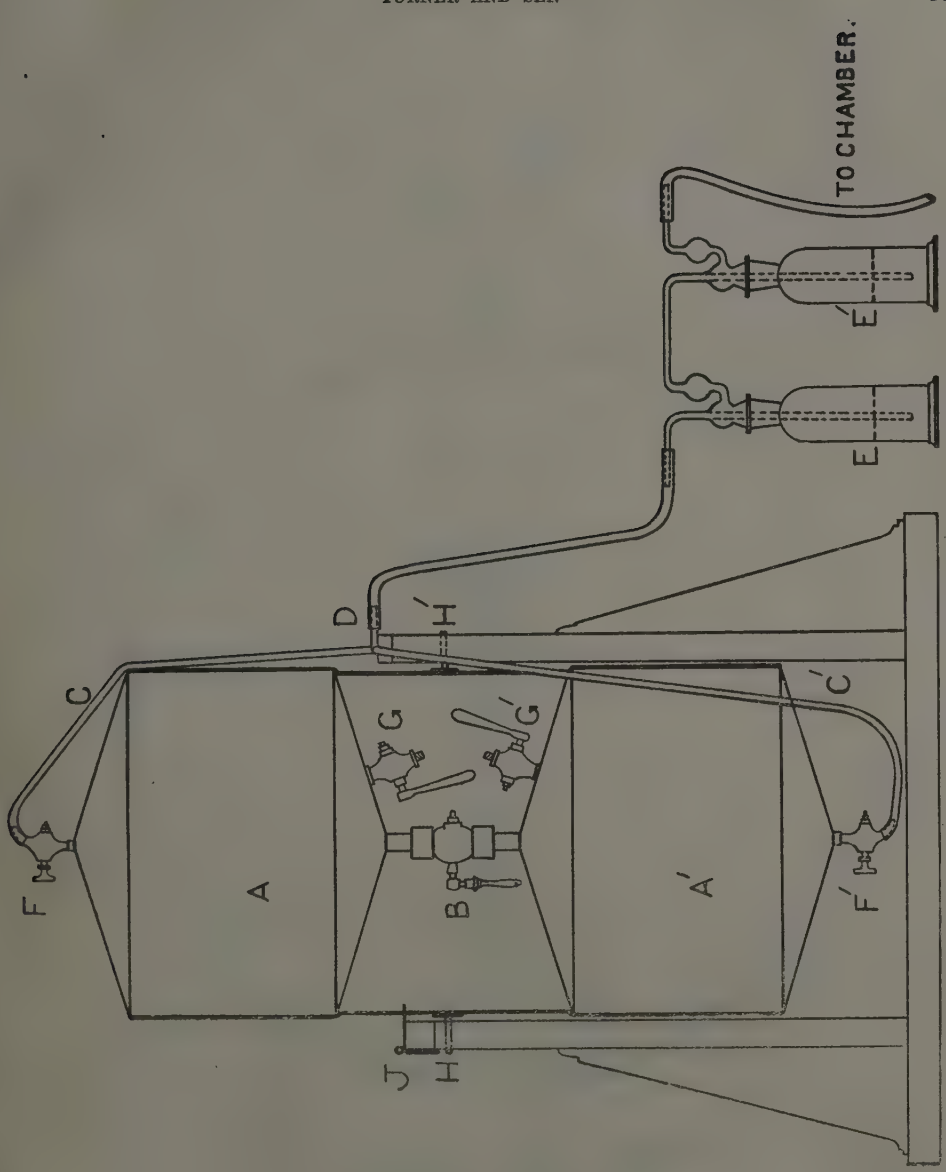


Fig. 3. Sampling Apparatus in Chamber Experiments.

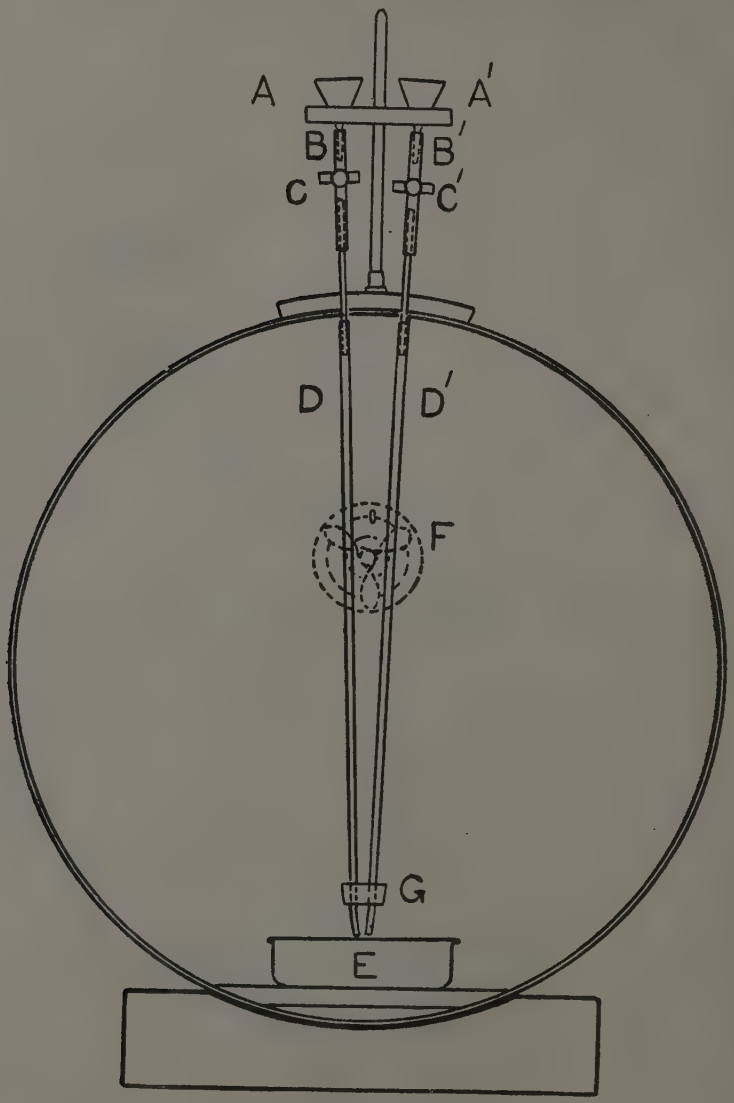


Fig. 4. Section of Steel Chamber.

Full-Scale Fumigation Experiments in Barge.

3. Full-Scale Experiments.

The full-scale experiments were carried out on a steel barge supplied by the Bombay Port Trust. The barge had two holds, only one of which was used. This hold had a capacity of about 3,000 cubic feet. For generating the HCN a Liston's Cyanide Fumigator was used, which was placed under a temporary shelter at one end of the barge.

The following account of the fumigator is based on the description given in the paper by Liston and Goré[1] (Figs. 5, 6, 7 and Plates XXV, XXVI and XXVII). The fumigator consists of a box A in which the HCN is generated. On the lid of this box a fan B, a petrol motor C with petrol tank W, and a chemical cabinet D are fixed. The petrol motor is capable of driving the fan at 3,600 R.P.M., and at this rate of revolution the fan can deliver 1,200 cubic feet of air per minute along a length of pipe at a pressure of 6 inches on a water gauge. In the chemical cabinet are two glass containers E, E′ made from Winchester quart bottles from which the bottoms have been removed. The inverted bottles are placed in a stand F. The mouth of each bottle is fitted with a rubber cork G, G′ through which passes a glass tube H, H′. These glass tubes are for the purpose of conducting the solutions placed in the respective containers to the generating box, in which the two solutions are caused to react with one another. The glass tubes are therefore respectively connected by rubber tubings K, K′ on each of which a screw clamp L, L′ is fixed, to two other glass tubes, M, M′ passing through a large rubber cork N inserted in a hole in the top of the generating box. The latter glass tubes overhang a small platform or channel O which is fixed below the cork and which has a slight slope towards the side of the box. The sloping channel is fitted with small baffle plates, so that the solutions flowing from the containers are thoroughly mixed as they flow along the channel. One container E is reserved for a solution of sodium cyanide, and the other E′ for a strong solution of sulphuric acid. A slightly hollowed and perforated lead cover P, P′ is placed over the upper end of each bottle. These covers serve to strain off particles of matter (sawdust, etc.) which may be suspended in the solutions and which might otherwise block the various tubings; they also prevent any splashing of the solutions by vibration when the motor is working. The gas is generated by allowing 50 per cent. solutions of sodium cyanide and sulphuric acid respectively to flow at an equal rate upon the sloping channel within the box, by so adjusting the screw clamps on the rubber tubings referred to above that the solutions in the two containers fall at the same rate in line with one another.

The chemical cabinet also contains two copper vessels Q, Q′ which are used to aspirate a measured quantity of the atmosphere from the compartment under treatment. The vessels are of such a capacity as to deliver 5 litres of water from the one to the other, when the small outlets R, R′ fixed near the bottoms of the vessels

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[1] W. G. Liston and S. N. Goré. The Fumigation of ships with Liston's Cyanide Fumigator: *Journal of Hygiene*, vol. XXI, No 3, May 18, 1923.

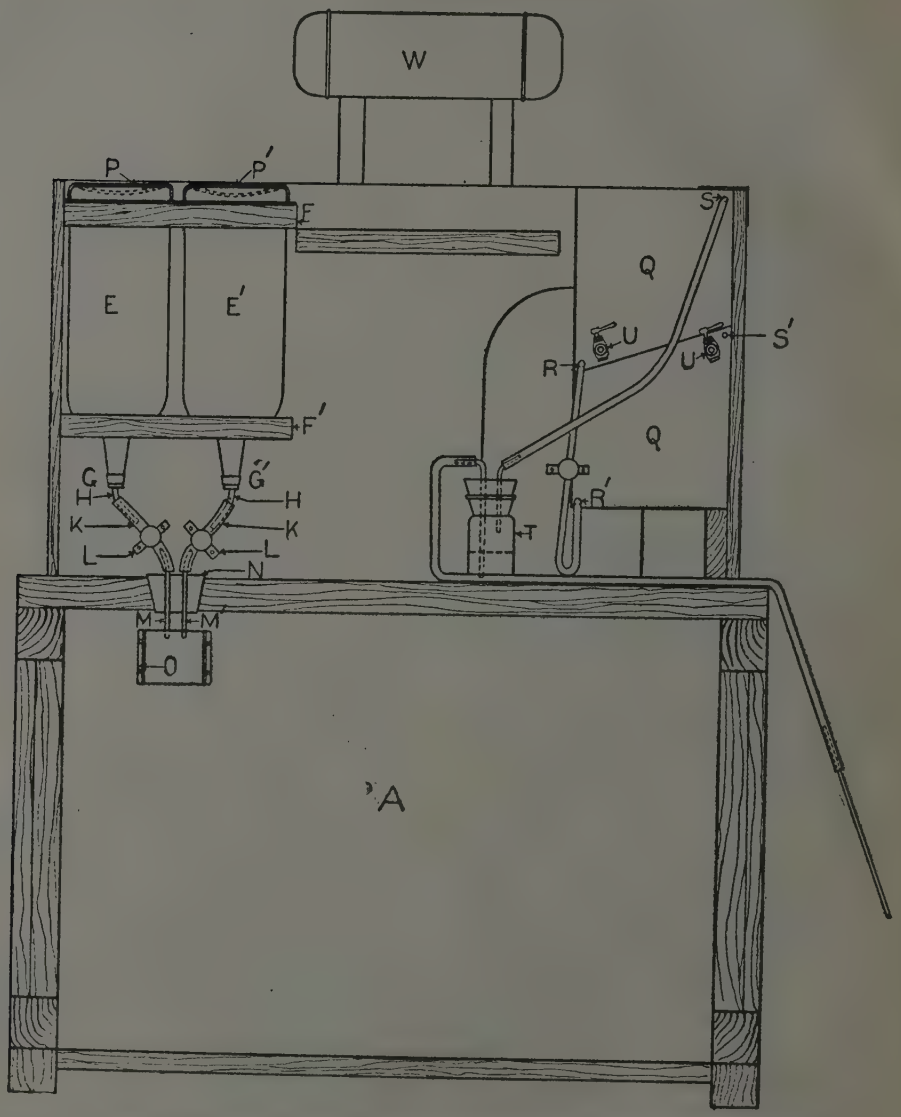
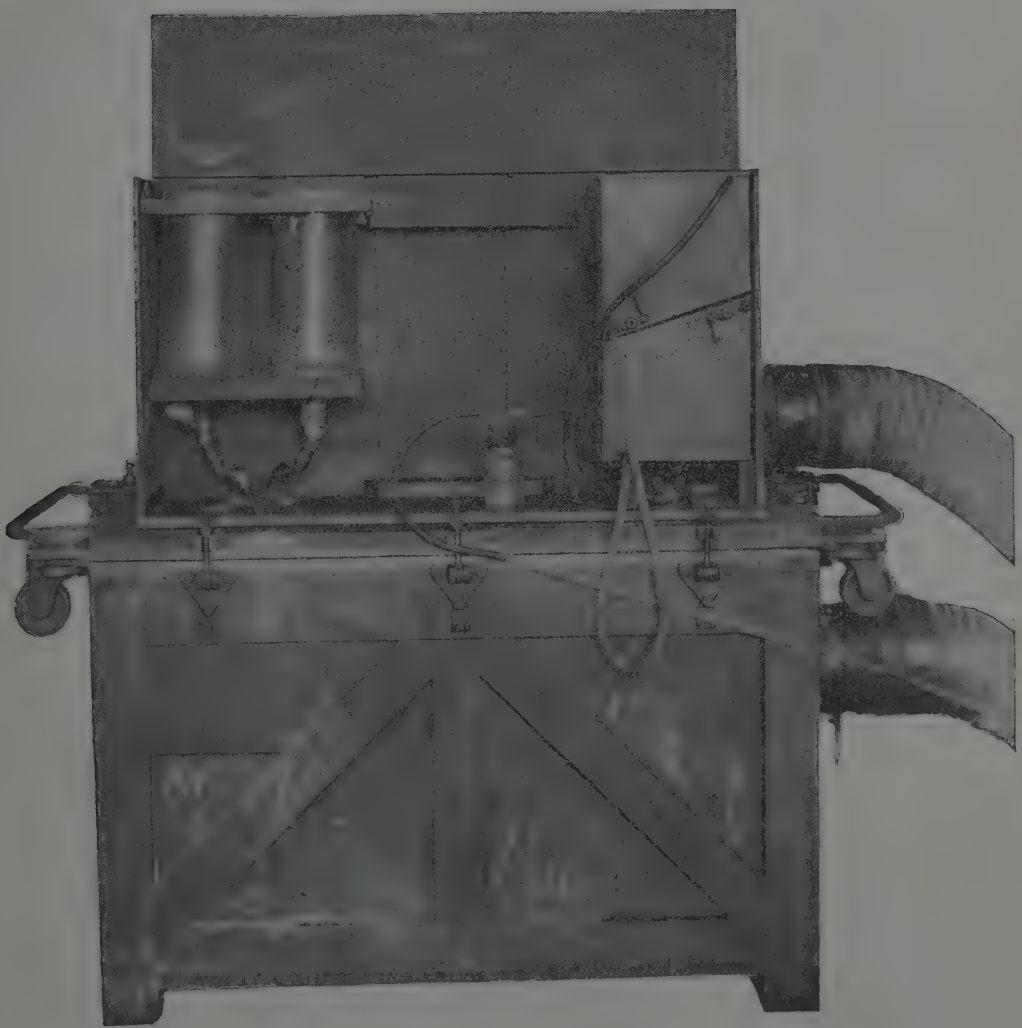
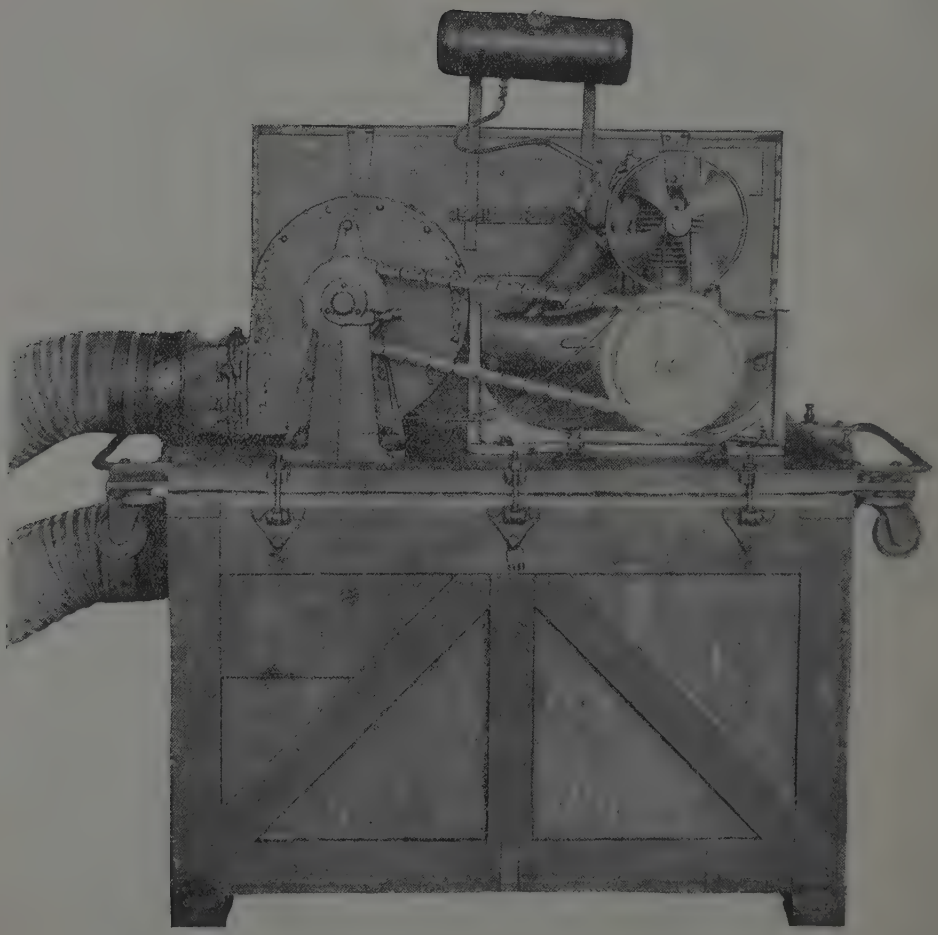


Fig. 5. Side Elevation (Section Through Chemical Cabinet) of Liston Cyanide Fumigator.



Liston Cyanide Fumigator—showing Chemical Cabinet.

PLATE XXVII.



Liston Cyanide Fumigator—showing Engine and Fan.

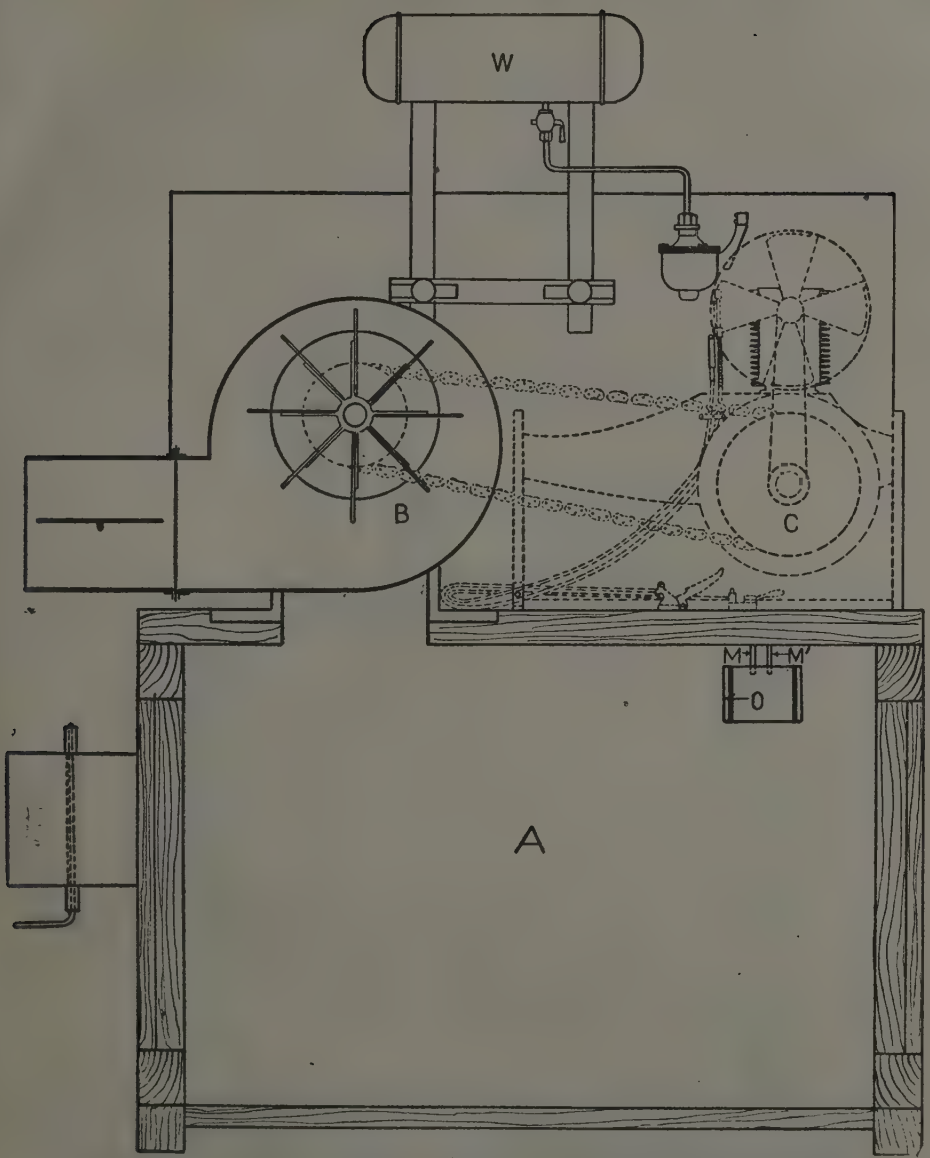


Fig. 6. Side Elevation (Section Through Engine and Fan) of Liston Cyanide Fumigator.

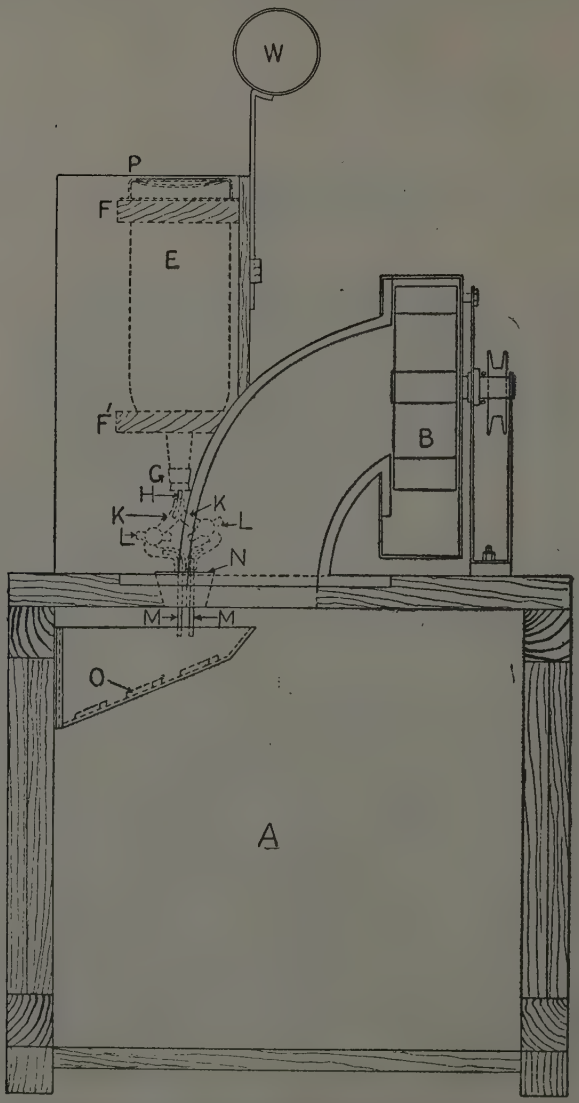


Fig. 7. End Elevation (Section Through Chemical Cabinet and Fan) of Liston Cyanide Fumigator.

are connected together by rubber tubing and when the one containing the water is placed on top of the empty vessel. A small tube S, S′ fixed near the top of each vessel enables either of them to be connected at will to a gas-absorption vessel T. Each vessel is also provided with a tap U, U′. During an estimation U is closed and U′ is open, thus allowing the air in Q′ to be replaced by water from Q. The other details and the *modus operandi* are similar in effect to those already described for the sampling and testing apparatus used in the experiments on the one-bale-scale; when the positions of Q, Q′ are reversed, the functions of R, R′ and S, S′ are interchanged.

The strength of the standard silver nitrate solution used in the full-scale experiments was 1·897 grams $AgNO_3$ per 1,000 c.c. solution. If x c.c. of this solution are used in the titration then $(x \times 10)$ represents the number of parts of HCN by volume per 100,000 parts of the atmosphere within the barge, at normal temperature and pressure.

III. Blank Experiments: Chemical Difficulties.

I. Small-Scale Experiments.

In the first place blank experiments were carried out to test the gastightness of the apparatus. The following results are an example of the degree of satisfaction which the apparatus normally gave in this respect, using a charge of 0·10 gram sodium cyanide :—

Table II.

Date	Time	Volume displaced	Temperature °F.	HCN-concentration	
				Parts per 100,000 by volume	Percentage of theoretical value
1925—		c.c.			
April 16	2-30 p.m.	250	87	282	66
„ 16	4-0 „	250	87	282	66
„ 17	9-15 a.m.	250	85·5	180	42
„ 17	2-15 p.m.	250	87	246	56
„ 17	4-0 „	250	87	252	59
„ 18	12-0 noon	250	86·5	246	56
„ 20	11-0 a.m.	250	87	246	56
„ 20	11-35 „	250	87	246	56

It will be observed that the above test lasted for 4 days without opening up. The low result obtained at 9-15 a.m. on April, 17th may have been partly due to the effect discussed on pages 76—79, or it may have been due either to direct condensation of HCN or to condensation of moisture having occurred during the night with consequent solution of some of the HCN, which may not all have been regasi-

fied at the time of this determination (see page 95). With a smaller charge of 0·05 gram, the following results are fairly typical :—

TABLE III.

Date	Time	Volume displaced	Temperature °F.	HCN-concentration	
				Parts per 100,000 by volume	Percentage of theoretical value
1925—		c.c.			
February 19	8-35 a.m.	500	71	183	86
„ 19	12-15 p.m.	500	76·5	192	90
„ 19	4-15 „	500	77·5	190	89
„ 19	8-25 „	500	75·5	175	82

Over a period of 12 hours the changes in concentration have been comparatively small. In one or two cases, however, such a degree of consistency was not obtained in the results for the HCN-concentration ; the following is the most extreme example of the variation observed, when the charge of sodium cyanide used was 0·10 gram :—

TABLE IV.

Date	Time	Volume displaced	Temperature °F.	HCN-concentration	
				Parts per 100,000 by volume	Percentage of theoretical value
1925—		c.c.			
April 21	11-30 a.m.	250	89	240	56
„ 22	7-30 „	250	87	204	48
„ 22	11-30 „	250	88	162	38
„ 22	12- 5 p.m.	250	88	216	51
„ 22	2- 0 „	250	88	138	32
„ 22	3-10 „	250	88	210	49

These variations cannot be ascribed to leaks because some of the later determinations gave comparatively high values. With such a constant temperature it is difficult to believe that differences in concentration occurred within the desiccator or that the anomalies were due to condensation of HCN or to absorption and subsequent evolution of the HCN either in the liquid paraffin or in water of condensation. It may be added that the determination at 12-5 p.m. on April 22nd, 1925, was made because the previous determination made only half an hour before had given a result which was unexpectedly low. Such variations as this, however, were most unusual.

(i) *Effect of Moisture on the Cyanide-Acid Reaction.* When these experiments were first planned it appeared likely that moisture present in the desiccator atmos-

phere might give rise to difficulties in the event of any temperature changes. Thus if an experiment were started when the day temperature was 86°F. and the relative humidity 60 per cent. and if the night temperature were to fall to 70°F. the air would be saturated; with a higher day humidity or a lower night temperature, deposition of dew would occur accompanied by solution of HCN therein, with some disturbance in the concentration of HCN in the atmosphere within the desiccator. With a suitable rise in temperature the next morning the condensed water would evaporate, leaving no clue to the fact that the HCN-concentration had actually been lower during the night. It was evident that this difficulty might be accentuated if aqueous solutions were used to generate the HCN. If only two drops of water (0·075 gram) were added to the charge of cyanide, and if all this water were to be vaporised in the cyanide-acid reaction, it would entail the consequence that with the above day conditions the air would be saturated if the temperature fell to 74°F. only. Thus the effect of even a small amount of added water might apparently be considerable. It was therefore decided not to add any water to the charges of cyanide or acid but to use air-dry cyanide and ordinary concentrated sulphuric acid. In view of the considerations detailed below, however, this decision was modified at a later date, the risk of condensation of moisture being preferred to the other difficulties actually encountered. Moreover, experience showed that the temperature-range in the Laboratory, day and night, was so small that the difficulty which was feared at first was unlikely to eventuate.

It may be observed that the concentration obtained using 0·10 gram sodium cyanide was considerably less than twice that obtained using 0·05 gram sodium cyanide. Even in the latter case the concentration obtained was less than the theoretical, assuming that the sodium cyanide was pure, that all the HCN radical was converted into HCN, and that all the HCN was evolved. Thus, in the experiments above quoted, with a charge of 0·10 gram sodium cyanide (Table II) the actual initial concentration was 56 per cent. of the theoretical value, while with 0·05 gram sodium cyanide (Table III) it was 86 per cent. of the theoretical value. It was in fact found that a certain quantity of HCN remained in the solution in the crucible, and allowing for the presence of a certain amount of impurity in the cyanide, the higher figure of 86 per cent. of the theoretical value might be regarded as satisfactory. It was not obtained invariably, however, even when charges of only 0·05 gram sodium cyanide were employed. Thus, while in the case already cited the initial HCN-concentration observed was 86 per cent. of the theoretical value, in other experiments with a charge of 0·05 gram sodium cyanide the maximum percentages of the theoretical value obtained were only 77, 66 and 61 respectively; on the other hand, in some experiments in which a charge of 0·10 gram sodium cyanide was used the percentages were 83, 54, 44, and 37 respectively, although the HCN-concentration remained fairly constant throughout each experiment at the value given.

In view of the general superiority of the figure with the smaller charge of sodium cyanide, it was thought that these differences might be caused by differences in the temperature attained in the reaction; the temperature attained would tend to be higher with the larger charge, as dissipation of heat would tend to be slower in this case, and at the higher temperature some side reaction or secondary reaction leading to decomposition of the HCN produced might conceivably occur; thus, according to Thorpe's Dictionary of Applied Chemistry[1] when concentrated sulphuric acid is caused to react with (dry) cyanide, carbon monoxide and ammonia are produced. A possible alternative explanation is that the action of concentrated sulphuric acid on the dry cyanide is so violent that an indefinite amount of the latter is scattered without taking any part in the reaction.

Moreover, it appeared that the varying results with a given charge of cyanide might be due to sodium cyanide being a hygroscopic substance, different quantities of moisture having been absorbed by the cyanide in different experiments; such differences in the amount of absorbed moisture are almost certain to have occurred in the earlier experiments for which air-dry cyanide was frequently weighed out some time before it was used. The violence of the cyanide-acid reaction and the temperature attained would probably be affected by the amount of moisture present. Some experiments were therefore carried out at a later date in which a few drops of water were added to the charges of dried cyanide, and also to the sulphuric acid used to generate the HCN. Whether the explanation be that the water keeps down the temperature or the violence of the reaction, the result was that large increases were in fact produced in the HCN-concentration attained, as is shown by the following examples. In the first series, Table V, potassium cyanide was used; the amount of water added to the cyanide was two drops (0·075 gram) per 0·10 gram potassium cyanide.

TABLE V.

Date	Charge of potassium cyanide 0·10 gram	Volume displaced	Temperature °F.	HCN-concentration	
				Parts per 100,000 by volume	Percentage of theoretical value
1925—		c.c.			
August 20	Without water	1,500	83	141	45
„ 20	Do.	1,500	84	137	44
1925—		c.c.			
August 20	With water	1,500	84	219	70
„ 20	Do.	1,500	83	224	71

In the second series, Table VI, sodium cyanide was used, sometimes dry (dried by long exposure over fused calcium chloride), and sometimes moistened with water.

[1] Thorpe's Dictionary of Applied Chemistry, vol. II, 1921, 467.

TABLE VI.

Expt. No.	Date	Charge of sodium cyanide	Amount of conc. sulphuric acid added	Mean temperature °F.	Initial HCN-concentration		Final HCN-concentration		Period between initial and final determinations of HCN-concentration Hours	Amount of sodium cyanide left undecomposed in crucible (%)
					Parts per 100,000 by volume	Percentage of theoretical value	Parts per 100,000 by volume	Percentage of theoretical value		
	1926—									
1	Feb. 26	0·10 gram and 1 drop water	0·6 c. c. and 3 drops water	82	303	71	270	63	19	...
2	Mar. 2	ditto (Duplicate)	ditto (Duplicate)	82	315	74	303	71	1½	1·0
3	Feb. 24	0·10 gram and 2 drops water.	0·6 c. c. and 3 drops water.	83	309	72	285	67	19	...
4	Mar. 3	ditto (Duplicate)	ditto (Duplicate)	84	324	76	309	72	1½	1·0
5	Feb. 25	0·10 gram and 3 drops water.	0·6 c.c. and 3 drops water.	84	312	73	297	69	22	...
6	Feb. 26	0·10 gram (dried)	0·6 c.c (no water)	82	180	42	156	36	22	8·0
7	Mar. 4	ditto (Duplicate)	ditto (Duplicate)	82	112	26	102	24	2	6·1
8	Mar. 4	ditto (Triplicate)	ditto (Triplicate)	82	162	38	153	36	2	5·7

It is evident from these results that the presence of a small quantity of water causes a much higher HCN-concentration to be attained. Another striking feature is the comparative constancy in the figure obtained for the initial HCN-concentration when diluted acid is used to generate the HCN and some water has been added to the charge of cyanide. It is immaterial whether the water added to the cyanide charge of 0·10 gram be one drop, two drops or three drops. The average of the initial values obtained under these conditions is 312 parts HCN per 100,000 ; this corresponds to a charge of cyanide equal to 73 per cent. of the theoretical value. This is practically the same as was obtained with the moistened potassium cyanide (Table V) and in many other experiments.

The triplicate tests with specially dried cyanide and pure concentrated sulphuric acid exhibit considerable inconstancy in the amount of HCN generated ; the highest value for HCN-concentration, 180 (experiment 6), is about 60 per cent. higher than the lowest, 112 (experiment 7). The average of the three values in the triplicate experiments 6, 7, 8 above, is 151, which represents only 35 per cent. of the theoretical value for the HCN-concentration from the given charge of sodium cyanide. This very low value—which is much lower than that generally obtained in experiments where no water was deliberately added to the charge of cyanide—is probably to be ascribed to the special care taken in drying the cyanide : the " air-dry " material used in the earlier experiments would no doubt have contained hygroscopic moisture.

One other point may be mentioned in connection with Table VI, *viz.*, that a greater percentage of the cyanide remains undecomposed when quite dry cyanide is used in the reaction—the average values being 6·6 per cent. undecomposed with dry cyanide and 1·0 per cent. undecomposed with moistened cyanide and diluted acid. This difference is a further indication of the greater violence of the action with dry cyanide.

(ii) *Absorption of HCN by concentrated Sulphuric Acid.* One other difficulty may be mentioned. In the earlier experiments it was sought to maintain a dry atmosphere inside the desiccator by placing therein concentrated sulphuric acid contained in small glass dishes. But under these conditions it was found that the HCN-concentration gradually fell off with time. Thus, the following example is fairly typical :—

TABLE VII.

Date	Time	Charge sodium cyanide added (gram)	HCN-concentration	
			Parts per 100,000 by volume	Percentage of theoretical value
1925—				
February 12	4-15 p.m.	0·05	111	52
„ 12	7-45 „	„	75	35
„ 12	8-15 „	0·05	156	37
„ 13	7-45 a.m.	„	85	20

This table shows that after 15½ hours from the beginning of the experiment the HCN-concentration obtained from a total charge of 0·10 gram sodium cyanide had fallen to 85 parts HCN per 100,000, representing only 20 per cent. of the theoretical value. Examination of the apparatus revealed no obvious source of leakage. It finally seemed possible that the liquid paraffin had become contaminated with water and so rendered absorbent of HCN, but no trace of moisture could be detected therein. However, a desiccator experiment was tried in which concentrated sulphuric acid was used as the displacing liquid instead of liquid paraffin, as it was thought that there would then be no question of any absorption by the displacing liquid. The experiment yielded the following result :—

TABLE VIII.

Date	Time	Charge sodium cyanide (gram)	HCN-CONCENTRATION	
			Parts per 100,000 by volume	Percentage of theoretical value
1925—				
February 17 . .	11-25 a.m.	0·10	201	47
„ . .	12-25 p.m.	..	75	17
„ . .	1-25 „	..	36	8

This table shows that, instead of remaining constant, the concentration actually fell to 8 per cent. of the theoretical value in less than 2 hours, and the unexpected conclusion was therefore arrived at that *even concentrated sulphuric acid absorbs HCN*. In subsequent experiments, therefore, the dishes of the sulphuric acid were omitted, and no further trouble of this kind was experienced.

2. ONE-BALE SCALE EXPERIMENTS.

(*a*) *Wooden Chamber Experiments.*

It was not found possible to maintain a constant concentration of HCN in any of the experiments in the wooden chamber when the exposure was of comparatively

long duration. The following series of results is a fairly typical example of those obtained, the charge being 7 grams sodium cyanide dissolved in 15 c.c. water, acted on by 20 c.c. of 50 per cent. sulphuric acid.

TABLE IX.

Date	Time	HCN-concentration	
		Parts per 100,000 by volume	Percentage of theoretical value
1924—			
April 10	1-15 p.m.	(Experiment started)	
	1-30 „	147	64
	2-0 „	133	58
	2-30 „	119	52
	3-0 „	125	54
	3-30 „	125	54
	4-0 „	125	54
April 11	11-45 a.m.	55	23
	1-0 p.m.	51	22

Thus in 24 hours the HCN concentration fell to one-third of its initial value, showing that considerable leakage had occurred. It may be observed that in spite of this leakage, the HCN-concentration registered a quarter of an hour after the generation of the HCN was 64 per cent. of the theoretical—a figure agreeing with the general experience when water was present during the cyanide-acid reaction (pages 94—98).

(b) Steel Chamber Experiments.

The blank experiments in the steel chamber are summarized in the following table :—

TABLE X.

Blank Experiments in Steel Chamber.

Expt. No.	Date	Time	Duration of exposure (hours)	Charges		HCN-concentration	
				Sodium cyanide	Sulphuric acid	Parts per 100,000 by volume	Percentage of theoretical value
	1925—						
1	June 6	9-20 a.m.	(started)				
		9-50 „	½	20 grams in 20 c.c. water.	20 c.c. with 20 c.c. water.	296	64
		5-15 p.m.	8	..	..	274	59
	June 8	9-5 a.m.	48	..	..	184	40
2	June 15	11-45 a.m.	(started)				
		12-30 p.m.	¾	2 oz. in 2 oz. water.	2 oz. in 2 oz. water.	560	40
		2-15 „	2½	..	..	611	44
		4-15 „	4½	..	..	603	43
	June 16	9-45 a.m.	22	..	..	520	37
	„ 17	9-30 „	46	..	..	404	29

The first blank experiment in which the loss during 48 hours was only 38 per cent. of the initial concentration, was confirmed by the second blank experiment in which large charges were used, and in which the loss after 46 hours was in about the same proportion as in the first experiment. This showed that the steel chamber was sufficiently gas-tight for this work.

IV. Experiments with the Grain-weevil (*Sitophilus oryzae*.)

It has already been mentioned that the object of these experiments was to determine the lethal power of HCN for the grain-weevil, and its dependence upon concentration and duration of exposure. It was only at a later stage that it was found to depend also upon the temperature ; this effect is no doubt a consequence of the reduced vitality of the weevils at higher temperatures, a feature to which Dr. Hunter had indeed already drawn attention as regards the boll-weevil.

1. Small-Scale Experiments.

The experiments fall into two series. Series I happened to be carried out during the "cold wave" prevalent in Bombay in February 1925, while Series II was carried out during the hot weather of the following May.

A summary of the results is given in the tables below. In Series II it was intended at first to study more closely the results obtained with about 18 hours' exposure, in view of the results obtained with this exposure in Series I, when only one weevil out of 20 had not been killed outright.

Table XI.

The Effect on Grain Weevils of Exposure to HCN—Series I.

Experiment No.	Date	Period of exposure (hours)	Charge sodium cyanide (gram)	Mean temperature °F	Average HCN-concentration		No. of weevils present	Effect of Exposure on Weevils		
					Parts per 100,000 by volume	Percentage of theoretical value		Did not revive	Revived but died within 48 hours	Revived and lived more than 48 hours
	1925—									
1	Feb. 2	4	0·05	76	114	54	10	0	0	20
2	,, 3	8	0·05	77	141	66	10	2	5	3
3	,, 4	12	0·05	77	101	47	10	8	2	0
4	,, 9	12	0·05	75	185	86	10	10	0	0
5	,, 5	16	0·05	73	86	40	10	4	6	0
6	,, 6	16	0·10	73	101	24	20	14	6	0
7	,, 12	16	0·10	72	107	25	20	17	3	0
8	,, 18	16	0·05	71	173	81	10	7	3	0
9	,, 19	18	0·05	76	152	71	20	19	1	0
10	,, 17	20	0·10	76	322	75	10	10	0	0

Table XII.

The Effect on Grain Weevils of Exposure to HCN—Series II.

Experiment No.	Date	Period of exposure (hours)	Charge sodium cyanide (gram)	Mean temperature °F	Average HCN-concentration		No. of weevils present	Effect of Exposure on Weevils		
					Parts per 100,000 by volume	Percentage of theoretical value		Did not revive	Revived but died within 48 hours	Revived and lived more than 48 hours
11	1925—May 29	9	0·05	86	125	59	20	4	16	0
12	,, 30	9	0·05	85	135	63	18	12	6	0
13	,, 26	12	0·10	88	220	51	20	20	0	0
14	,, 26	12	0·05	88	139	65	20	20	0	0
15	,, 28	12	0·05	86	144	68	20	18	2	0
16	June 1	16	0·05	84	111	52	20	19	0	1
17	,, 2	16	0·05	82	133	62	20	19	1	0
18	May 20	19	0·10	88	141	33	20	20	0	0
19	,, 21	19	0·10	87	174	41	20	20	0	0
20	June	19	0·05	82	113	48	20	15	2	3
21	,, 5	19	0·05	81	126	59	20	18	1	1
22	May 22	22	0·10	86	140	33	20	20	0	0
23	June 8	24	0·05	84	100	47	20	20	0	0
24	,, 9	24	0·05	84	104	49	20	20	0	0

The first two experiments (Nos. 18, 19) performed in Series II, however, resulted in all weevils being killed outright after 19 hours' exposure. A similar result was obtained in the next exposure, which was for 22 hours (No. 22), and for the two following exposures (Nos. 13, 14) which were for 12 hours. A third exposure for 12 hours did not give the same result, as two weevils out of the 20 did show signs of life some time subsequent to their removal from the desiccator, but they died soon afterwards. Two experiments were then made with only 9 hours' exposure each: with this exposure a fairly large percentage of the weevils recovered, but died soon afterwards. It was at once apparent that the results in Series II were very different from those in Series I. Thus, taking into consideration all results for 12 hours' exposure or more in Series I, 21 weevils out of 110 revived but in Series II only 6 revived out of 240. The most striking general difference between Series I and Series II is that the first set of experiments was

carried out in the cold weather and the second set in the hot weather ; it therefore appears to be the case that the higher temperatures prevalent during Series II are responsible for the greater ease of killing in that Series. This is not an unexpected result when it is borne in mind that the grain weevils were much more lethargic and had a reduced vitality in the hot weather, causing them to die in larger numbers than during the cold weather,—thus confirming the observations on the boll weevil itself referred to by Dr. Hunter. That the temperature played an important part appears also from a closer examination of the results obtained in the hot weather, Series II. Thus, in the 12 hours' exposure, excluding No. 13 where the HCN-concentration was comparatively high, and comparing only Nos. 14 and 15 (HCN-concentrations 139 and 144 parts respectively per 100,000), it is noteworthy that at 88°F. all 20 weevils were killed outright, while at 86°F. two weevils out of the 20 weevils revived in not more than 16 hours, but died some hours afterwards. As an isolated instance this might be regarded as a mere chance, two of the weevils having rather more vitality than any of the others. But the case is strengthened when a similar instance occurs in the 16 hours' exposure, No. 17, where at a similar HCN-concentration one weevil revived out of 20 (but died soon afterwards) the temperature being lower at 82°-83°F. The results for the 19 hours' exposures yield further confirmation, for in No. 18 the HCN-concentration was the same as in the other experiments quoted and none of the weevils revived, the temperature being 87°F., but in No. 20 at 82°F. and No. 21 at 81°F., some of the weevils revived in each case, although here the result might be attributed to the average HCN-concentration being rather low, (113 and 126 parts HCN respectively per 100,000).

Although it is most satisfactory no doubt to ensure that all the weevils are killed outright and do not revive however favourable may be the circumstances, it may be pointed out that it is most probable that no danger is to be apprehended from weevils which have been gassed for about *12 hours* at a concentration of 150 parts HCN per 100,000. The weevils, two or three minutes after being gassed, display no movement (this may of course be " shamming " in the first instance), but on being removed after the 12 hours' exposure and placed in fresh air, they seldom revive until some hours have elapsed. But when they do revive they are evidently most uncomfortable, periodically lying on their backs and kicking their legs—walking unsteadily an inch or so and again turning on their backs, etc., and displaying no interest in food which is made available for them ; and almost invariably they die some hours later without ever having partaken of any of the food.

In taking precautions against the weevil, however, it is necessary to provide against the possibility of those conditions prevailing which are most favourable to the weevils. Bearing all the above facts in mind, the conclusion is reached, so far as the grain weevil (*Sitophilus oryzae*) is concerned, that an exposure for 20 hours under Bombay conditions to a concentration of 150 parts HCN per 100,000 (by volume) will be sufficient to ensure its destruction.

2. Intermediate-Scale (Wooden Chamber) Experiments.

The various results obtained in the wooden chamber tests on *Sitophilus oryzae* are summarized in the table below :—

Table XIII.

Experiment No.	Date	Time		Duration of exposure (hours)	Concentration parts HCN per 100,000		Effect on Weevils	
		Start	Finish		Start	Finish	Alive	Dead
	1924—							
1	Mar. 26 .	11-15 a.m.	2-15 p.m.	3	156	134	20	0
2	„ 27 .	12-15 p.m.	3-30 „	3	296	260	200	0
3	„ 31 .	11-30 a.m.	2-30 „	3	348	308	20	0
4	„ 28 .	11-35 „	2-30 „	3	360	314	200	0
5	Apl. 1 .	11-45 „	2-45 „	3	400	580	12	8
6	„ 2 .	10-50 „	4-50 „	6	324	240	40	0
7	Mar. 26 .	4-0 p.m.	..	..	160	..	..	..
	„ 27 .	..	11-20 a.m.	19	..	90	0	20
8	Apl. 11 .	3-0 p.m.	..	..	161	..	..	..
	„ 12 .	..	11-45 a.m.	21	..	78	0	80
9	„ 10 .	1-15 p.m.	..	..	147	..	..	..
	„ 11 .	..	1-15 p.m.	24	..	51	0	80
10	„ 2 .	5-3 p.m.	..	..	160	..	..	..
	„ 3 .	..	5-5 p.m.	24	..	78	0	40

It will be noted that these experiments were carried out previous to those in the fumigation desiccator. From them it appeared that short exposures at comparatively high concentrations of HCN would not be as satisfactory as longer exposures at lower concentrations. All the 3-hours' exposures were quite unsatisfactory ; even with a concentration of about 500 parts per 100,000 (Expt. 5) no fewer than 12 out of 20 weevils remained alive after this period of exposure. Again, the 6-hours' exposure at an average concentration of over 280 parts per 100,000 was also ineffective. On the other hand, all the longer exposures—19 hours and upwards—proved effective with an initial concentration of about 160 parts per 100,000 and an average concentration of about 115 parts per 100,000. These figures agree fairly

well with those already referred to in Series II, page 103, dealing with the determination of lethal concentration of HCN for the grain weevil under hot-weather conditions.

Conclusion. The results of this division may therefore be summed up in the conclusion that to ensure the extermination of grain-weevils under Bombay conditions, it is sufficient to expose them for a period of 20 hours to a HCN-concentration of 150 parts per 100,000 by volume.

V. Experiments with the Mexican Boll-weevil (*Anthonomus grandis*).

These experiments were carried out in the Delta Laboratory, Tallulah, La., U. S. A., where numbers of boll-weevils were available for the purpose.

The actual results obtained by Mr. G. L. Smith in October-November, 1924. and by Messrs. F. H. Tucker and V. V. Williams in November, 1925, are reproduced in Appendix III. It will be observed that the experiments were of two types—box experiments and desiccator experiments. The former were designed to reproduce the conditions of the wooden chamber experiments (page 84), while the latter were carried out in the same way as the desiccator experiments on the grain-weevil (pages 75—84).

It is interesting to note that the boll-weevil displays in these experiments a susceptibility to the effects of temperature similar to that displayed by the grain-weevil. Thus, in Table I, Appendix III, experiments 22 and 23 were of the same duration (2 hours) at the same initial HCN-concentration (375 parts per 100,000), but whereas in the former the maximum temperature was 73°F. and 8 out of 25 weevils were not killed, in the latter the maximum temperature was only 63°F. and not one weevil was killed out of 25.

Another point of great interest and importance is that hibernated weevils are shown to be much more susceptible to HCN than field weevils. For example, from Table II, Appendix III, it is seen that the hibernated weevils were all killed in every single experiment—even with the lowest HCN-concentration (192 parts per 100,000) after only 5 hours' exposure at a temperature of about 63°F. (experiment nos. 27 and 30); whereas in experiment no. 26 at the same temperature but at a higher HCN-concentration (230 parts per 100,000), the same exposure resulted in the deaths of only 60 per cent. of the field-collected weevils.

It so happens that practically no danger is to be apprehended from the active weevils as no food would be available for them on the voyage. If, therefore, the fumigation procedure is based on the greater vitality of field (active) weevils and only hibernated weevils have actually to be feared, it is evident that the chances of any such weevils surviving the fumigation are infinitesimal.

In examining in detail the results for the experiments to determine the lethal power of HCN for the boll-weevil, it will be simpler to consider first the results of

the box-experiments, Table 1, Appendix III. The following is the description of the box used : " A box six feet by three feet by three feet internal measurement was constructed of one inch A1 pure lumber and all fittings felted and stripped on the outside, making the box as near air-tight as possible. The joining of the box and border of the door were felted so that when closed the two feltings meshed. The sodium cyanide was placed in a crucible near the centre of the box on the floor and the acid was poured in through a glass stop-cock funnel which was located in the top of the box." From his results (Table I, Appendix III) Mr. Smith concluded " that the concentration of 150 parts HCN gas to 100,000 parts space is too weak to kill the weevils, while twice this strength would be doubtful without further study. However, it appears that three times this concentration (450 parts HCN to 100,000 parts space) could be used with a fair degree of certainty in fumigation 2-hour periods, provided the temperature was not lower than 80°F." Messrs. Tucker and Williams used the same box and as a result of their experiments with this box and with the desiccator came to a similar conclusion : " Judging from a detail study of box tests it is seen that for all practical uses a concentration of 450 parts of HCN to 100,000 parts air by volume over a two-hour period should give 100 per cent. mortality as a fumigant for the boll-weevil in any average fumigation plant."

So far as the box experiments are concerned, however, it has to be remembered that the HCN-concentration assigned in any particular experiment is a calculated value only. The results quoted on page 105 show that the actual HCN-concentration attained is always less, and in certain circumstances may be very much less, than the calculated HCN-concentration. Moreover, in the box experiments described in division II, where actual determinations of HCN-concentration were made, the HCN-concentration fell continuously so that the final HCN-concentration obtained during a 24 hours' exposure was only about one-third the initial concentration. It can therefore be assumed with a fair amount of certainty that the HCN-concentration actually experienced in the box experiments of Table I, Appendix III, will have been decidedly less than the calculated, especially when the exposure extended over a considerable period. In these circumstances it is hardly possible to sustain the conclusion from Table I that the concentration of 150 parts HCN per 100,000 by volume was not sufficient to kill the weevils in 20 hours. In view of the facts that very low temperatures were experienced, that the initial HCN-concentration must have been much less than the calculated, that there is a strong probability of considerable leakage during the 20 hours, and lastly, that a fairly high percentage of mortality was experienced in these exposures (roughly about 50 per cent.) —it appears legitimate to draw the conclusion that a concentration of 150 parts (actual) HCN per 100,000 *would* be sufficient under Bombay conditions to kill the weevils in 20 hours. Unfortunately, in the later experiments the concentration was never as low as 150 parts HCN per 100,000, and in no case did the exposure extend over a period of more than 12 hours. Consequently, the later

experiments, Table II, Appendix III, throw no direct light on the value of an exposure to a concentration of 150 parts HCN per 100,000 for a period of 20 hours.

The same objections as to the value of the initial HCN-concentration and the probable leakage cannot of course be taken to the results with high (theoretical) HCN-concentration which *have* been effective in killing the weevils. In these cases, indeed, it must be deduced that the effective HCN-concentration must have been considerably less than the nominal. In the later experiments (Nos. 3, 5, 6, Table II, Appendix III) a theoretical HCN-concentration of 450 parts per 100,000 has been sufficient to kill the weevils in 2 hours. In two other experiments (Nos. 18, 20, Table II, Appendix II) a HCN-concentration of 375 parts per 100,000 was sufficient to kill 29 weevils out of 30 in the one case and to kill all 30 weevils used in the second case. It would therefore appear from this experiment, carried out at a temperature of 70°F., that exposure for 2 hours to a HCN-concentration of 375 parts per 100,000 is almost certain to kill the weevils, while the rather higher HCN-concentration of 450 parts per 100,000 is certain to kill the weevils. Thus at high concentrations the boll-weevil appears to be decidedly more susceptible to the HCN than does the grain-weevil (compare page 105).

But as this investigation is directed to determining the *minimum* HCN-concentration necessary, the results obtained in the first series of experiments (Table I, Appendix III) cannot be disregarded, and both series of results must be considered in conjunction with one another. Referring to Table I, Appendix III, therefore, one observes that in experiment nos. 33, 34, 35, a theoretical HCN-concentration of 450 parts per 100,000 was only in one case sufficient to kill all the weevils in 2 hours. In experiment No. 35 one weevil and in experiment No. 33 six weevils remained alive out of 25 weevils exposed for 2 hours in each case. Similarly, when a theoretical HCN-concentration of 375 parts per 100,000 was used, there were numbers of cases in which the weevils were not killed. Yet the temperatures during these experiments were higher than those recorded during the later experiments, so that fai ure to kill the weevils would have been regarded as more likely to occur in the second series. Only two explanations of these results appear to be possible, *viz.*, either the vitality of the weevils in the first series was much greater than in the second series, or the average HCN-concentrations actually attained in the first series were a less proportion of the theoretical than in the second series. It is possible, of course, that both factors were present acting concurrently. But as for safety in working out a practical method of fumigation it is necessary to assume the operation of the most adverse circumstances, the effective theoretical HCN-concentrations in these short-period fumigations must be taken as the actual concentrations, so that taking all the experiments together it is not possible to act on the conclusion that exposure of the weevils for 2 hours to an atmosphere contain ng 450 parts HCN per 100,000 will certainly kill all the weevils. From these experiments, the only safe conclusion which is permissible is that at this HCN-concentration an exposure for 4 hours will certainly result in the killing of all the weevils.

The desiccator experiments may now be considered. The weevils used in these experiments were of two kinds, *viz.*, those collected from the field and those which " had gone into Spanish moss to hibernate. The reason for this change was due, of course, to the impossibility of collecting weevils from the cotton fields this year (*i.e.* 1925) later than November 10 ". As already indicated, perhaps the most remarkable fact about these desiccator experiments is the great disparity between the results obtained for field-collected weevils and for hibernated weevils. The results for field-collected weevils, however, show considerable variation: comparing No. 23 with No. 26, in the former only one weevil out of 30 remained alive after 4 hours' exposure to a HCN-concentration of 211 parts per 100,000, while in the latter 12 weevils out of 30 remained alive after a longer exposure (5 hours) to a rather higher HCN-concentration (230 parts per 100,000), at much the same mean temperature (66°F. in the former, 63°F. in the latter). The chief conclusion to be drawn from such conflicting results is that the vitality of these weevils fluctuates considerably. It is therefore safest to presume that the differences obtained in the first series of box experiments from those obtained in the later series of box experiments are to be attributed to this cause.

Some still later tests on active weevils only, carried out by Messrs. F. H. Tucker and G. L. Smith, are reproduced in Table III, Appendix III. Commenting on these results the authors state: " Of the thirteen tests in which the HCN gas was introduced, only one test failed to give 100 per cent. weevil mortality and this was a one hour exposure in which the gas concentration was 191 to 100,000 by volume. Twenty per cent. of the weevils were alive in this test. In the other tests the gas concentration was 300 or more to 100,000 with one exception. This was test No. 1 in which the gas concentration was 259 to 100,000 but the weevils were exposed to the gas for 5 hours in this test. A total kill resulted at all exposures, whether 1, 3 or 5 hours, when the gas concentration was not lower than 300 to 100,000. It seems that a one hour exposure is sufficient to produce a total mortality of weevils when a concentration of gas not less than 300 to 100,000 is used at moderate temperatures."

The surprising thing about these results is that the active weevils appear to be much more easily killed than in the earlier experiments. Indeed, they now appear to be more susceptible than hibernated weevils, not less. But bearing in mind the desirability of having a fairly large " factor of safety " it still appears best to base the practical procedure on those Experiments in which the boll-weevils display the greatest vitality.

Conclusion. If the practical procedure in fumigation were to be based entirely on these results it would be necessary to stipulate for an exposure for 4 hours to an *actual* HCN-concentration of 450 parts per 100,000. In view also of the results which were obtained with the grain-weevil, however, it is deduced that it would probably be equally effective to expose the boll-weevils continuously for 20 hours to a HCN-concentration which is not allowed to fall below 150 parts per 100,000.

VI. Absorption Experiments with Cotton and Cotton Bales.

1. Small-Scale Experiments.

(*a*) *General.*

The consideration of the absorption of HCN by cotton presents many difficulties in its theoretical aspects. To begin with, cotton is not a homogeneous solid—and its wax, cuticle, cellulose and protoplasm may react differently towards HCN. Moreover, the cotton contains moisture, the exact disposition of which is also unknown. If cotton were found not to absorb HCN the latter would be merely distributed through the air-spaces of the cotton. In this case one would expect that in desiccator experiments the atmospheric HCN-concentration from a given charge of cyanide would be rather higher with cotton present than with cotton absent, simply because the air-space available is reduced by the volume of the solid cotton substance. But if cotton *were* found to absorb HCN, with so many components present it would require much investigation to isolate the effect of each component, and to decide whether the observed results were due to the formation of one or more solid solutions or chemical compounds or to absorption effects. In the present experiments therefore it was only sought to answer questions having an immediate practical interest, chiefly to ascertain the extent, if any, of the absorption of HCN by the cotton and also the extent to which the gas is given off after the cotton is removed from the atmosphere containing the HCN. To this end the following series of experiments were carried out :—

(1) Blank experiments ;
(2) Experiments with loose and baled cotton ;
(3) Experiments with cotton with different moisture contents ;
(4) Experiments with cotton at different temperatures ;
(5) Aspiration experiments.

(i) *Air-space present in a cotton bale.* Bales of American cotton for export are heavily pressed, having a density of 23 lb. or more per cubic foot. As the mean specific gravity of the solid substance composing the cotton fibre is about 1·5, it follows that for cotton bales of the density mentioned, only about one-quarter of the volume is occupied by cotton, the remaining three-quarters being occupied by air ; some of this air lies between the individual fibres, some fills the central canal of the fibres and some fills the spaces in the fibrillar net-work forming the fibre-walls, Reliable figures are not available for the particular distribution of the total air-space, but considering the volume of an individual fibre, we shall probably not be far wrong if we allow a minimum volume of 80 per cent. for the solid substance, leaving say 10 per cent. for the interfibrillar space, and 10 per cent. for the central canal. In a bale of American cotton, therefore, pressed to the density mentioned,—of the 75 per cent. of the volume occupied by air, we may take 7·5 per cent. as occupied by interfibrillar air, 7·5 per cent. by air in the central canal, and about 60 per cent. by interfibre air.

(ii) *Absorption Experiments.* To determine the amount of HCN-absorption the previously weighed cotton (120 grams) was placed inside the desiccator, the HCN generated, and the first determination of HCN-concentration made after a quarter of an hour had elapsed, other determinations being made at intervals later.

In order to provide a further check on the accuracy of the results for the absorption of HCN by the cotton, a system of multiple charges was arranged for. Evidently the absorption capacity of the cotton is likely to be limited : when a series of charges is given in succession this limit will tend to be approached and additional charges will not be absorbed to the same extent, so that the HCN-concentration in the desiccator will tend to increase out of proportion to the magnitude of the additional charge given.

Diffusion of HCN into a mass of cotton might be expected to be most rapid when the interfibre air spaces are largest. Equilibrium would then be attained most rapidly when the cotton is in a loose condition. For this reason a number of experiments were made with loose cotton and a number also with cotton made up into small experimental bales having a density of about 10 lb. per cubic foot. With such bales the volume occupied by the solid substance would be only about 10 per cent., the remaining 90 per cent. being air-space. From these experiments it was hoped to gauge the maximum absorption which would have to be provided for. And as the *rate* of absorption would be expected to depend on the extent of the surface exposed in relation to the total volume of cotton, it was thought that some information could be derived in this connection from the tests on the experimental bales : this did not prove possible, however, no doubt because the experimental bales containing 90 per cent. air-space did not in effect differ sufficiently from the loose cotton to make it possible to decide whether any observed difference was due to the state of packing or to an inherent difficulty of determining the actual amount of absorption.

(iii) *Experimental difficulty.* The difficulty to which allusion has just been made arises from the fact that the method of experiment made it impossible to obtain exact knowledge of the HCN-concentration which would have been attained if the cotton had not been present. It was accordingly necessary to assume some figure for this HCN-concentration which would have been attained in the absence of the cotton. But mention has already been made of the fact that the initial HCN-concentration was very largely a matter of circumstances, being affected by the quantity of cyanide used as a charge and by the amount of water present. This initial HCN-concentration difficulty was well-recognized before most of these absorption experiments were carried out. An attempt was therefore made to reduce its magnitude in the first place by making blank experiments both before and after a series of absorption experiments ; the mean values obtained in the blank experiments were then taken as an indication of the values which would have been attained in the other experiments if the cotton had been absent. In addition, every effort was made to see that exactly the same routine was followed in each experiment

That this procedure was at any rate partially successful will be apparent from the much improved concordance of the figures for HCN-concentration obtained in comparable experiments as recorded in Tables XIV, XV and XVI. When, however, it was found at a later date that more consistent results for the quantity of HCN generated could be obtained by adding a little water, these absorption experiments were repeated under the new conditions.

(iv) *Effect of moisture content.* The experiments on cotton having different moisture contents were carried out as follows. Three duplicate sets of samples of American cotton were prepared, each sample weighing 60 grams. One pair of samples was placed in a large desiccator containing distilled water in its lower portion ; a second pair of samples was placed in a large desiccator containing concentrated sulphuric acid in its lower portion ; while the last pair of samples was placed direct in the fumigation desiccator. The samples were allowed to condition in the respective desiccators for different periods in different experiments. Further, when it was desired to prepare the experimental bales, the pair of samples in question was withdrawn from the desiccator, quickly tied up with cotton spindle banding, and replaced in the same desiccator and conditioned for a further period. When an experiment was to be performed, the duplicate samples were removed from the conditioning desiccator and at once transferred to the fumigation desiccator, the lid of which was immediately replaced and all connections made and sealed. The HCN was then generated and the usual procedure of the fumigation experiments followed : this has already been described.

Owing to the absence of any arrangement for controlling the humidity in the fumigation desiccator, it was not sought to control the actual condition attained by the duplicate sets of samples ; instead, at the end of a fumigation experiment, both bales were quickly withdrawn from the desiccator and placed in tins and sealed ; on one of them (and sometimes on both) a determination of the moisture content was made by means of the Baer Conditioning Oven ; on the other sample a determination was in some cases made of the HCN-content by aspiration experiments, as will be described later.

(v) *Effect of temperature.* From some of the experimental results it appeared as if the temperature was having some effect on the amount of absorption by the cotton. Some further experiments were therefore designed to elucidate this point. For this purpose, the whole of the fumigation desiccator was immersed up to the lid in a bath of water of which the temperature was controlled. The temperature was first kept at 30°C. (approximately room temperature at the time these experiments were made), then raised to 35°C. and finally to 40°C., the temperature being kept constant at each value for two hours ; two determinations of HCN-concentration were made at each temperature.

(vi) *Aspiration experiments.* The aspiration experiments, to which reference has already been made, were carried out with a view to checking if possible the conclusions as to HCN-absorption drawn from the differences in the HCN-concentration

observed with cotton absent or present in the fumigation desiccator. For this purpose one of the bales of cotton after fumigation was taken from the sealed tin and placed at once in a small desiccator just big enough to hold the bale ; in some cases the bale was transferred directly from the fumigation desiccator to the aspiration desiccator. Air was then aspirated through the small desiccator and the emergent air passed through Drechsel washing-bottles containing N/5 caustic soda (with potassium iodide solution) to absorb any HCN evolved. By using a double set of aspirators and wash-bottles the process was made continuous, two litres of air being aspirated through each set of Drechsel washing-bottles in turn. The aspiration was continued until the amount of HCN evolved was negligible.

(*b*) *Preliminary Absorption Experiments.*

The various results obtained will now be considered, beginning with some preliminary experiments on the fumigation and aspiration of two experimental bales.

(i) *Fumigation Experiment.* For this experiment a quantity of loose cotton was dried over concentrated sulphuric acid, made into two small bales weighing 63·5 grams each, and then re-conditioned over concentrated sulphuric acid.

TABLE XIV.

Results of a Preliminary Experiment on the Fumigation of Small Cotton Bales.

Time conditioned before baling . . . . . 27 hours.
Time conditioned after baling . . . . . 17 „
Moisture content (determined subsequently) . . . 4·6 per cent.
Charge of soduim cyanide . . . . . 0·10 gram.

Date	Time	Temperature °F.	HCN-concentration	
			Parts per 100,000 by volume	Percentage of theoretical value
1925—				
February 21 . .	9-0 a.m.	76	70	16
„ 21 . .	10-0 „	77	80	19
„ 21 . .	12-0 noon	83·5	120	28
„ 21 . .	2-0 p.m.	83	110	26
„ 21 . .	5-0 „	80	80	19
„ 23 . .	9-0 a.m.	77	60	14

The percentages of the theoretical value are much less than any obtained with no cotton present. It appeared clear, therefore, that some absorption by the cotton was taking place. Moreover, these figures reveal a remarkable parallel between the temperature and the concentration of HCN in the desiccator: the higher the temperature the higher the concentration in the desiccator and therefore the less the concentration of HCN in the cotton.

It was this experiment which led to the tentative conclusion that at higher temperatures the absorption by the cotton was less. Further experiments were made with a view to substantiating this result if possible. In point of fact, however, no such confirmation was obtained (compare pages 121, 128).

(ii) *Aspiration results.* In all, a volume of 62 litres of air was drawn through the desiccator containing one of the small experimental bales. From the titration results it was calculated that the equivalent quantity of sodium cyanide required for the HCN recovered from the cotton (allowing for 2 bales) is 0·011 gram. For the final concentration of HCN in the desiccator the equivalent amount of sodium cyanide which would be required is 0·014 gram. Hence the total amount of sodium cyanide which can be accounted for is 0·025 gram. As a charge of 0·10 gram sodium cyanide was actually used in the experiment, 0·075 gram, or 75 per cent., remains unaccounted for. Determinations of the sodium cyanide remaining in the residue in the crucible showed that this amounted to about 6 per cent., leaving still 69 per cent. to be accounted for. Some portion of this may have been due to irreversible chemical combination with substances present in the cotton, but alternative explanations are that impurity was present in the sodium cyanide, or that some of the HCN was decomposed in the reaction, or that either the fumigation apparatus or the aspiration apparatus was leaking, or that solution in the displacing liquid was taking place, or that considerable loss of HCN occurred during the transfer of the bale to the aspiration desiccator. Precautions were taken against some of these alternatives, and the most likely cause of the discrepancy appears to be initial decomposition or non-formation of the HCN, as discussed on page 96.

The results in other determinations varied from this figure but in all cases a large proportion was left unaccounted for. The following are some of the figures obtained; these figures include also the sodium cyanide left in the crucible in the desiccator.

TABLE XV.

Date	Sodium cyanide unaccounted for	Moisture content	Volume aspirated (litres)
	%	%	
1925—			
February 22 . . .	65	13·4	152
March 31 . . .	60	12·5	120

In view of the large percentage of sodium cyanide invariably left unaccounted for, these results could not be used to check those obtained by observing the change with time of the concentration of the HCN in the fumigation desiccator; and as they were not of a nature to throw light on the question as to the rapidity with which the cotton gave off HCN, these aspiration experiments were eventually discontinued.

(iii) *Multiple-charge experiments.* We may now proceed to the consideration of the multiple charge experiments. The results are given below in Tables XVI and XVII.

TABLE XVI.

Multiple-Charge Experiment.

(i) Damp cotton bales.

For this experiment a quantity of loose cotton was kept over water for 52 hours, baled, and re-conditioned over water for 43 hours.

Date	Time of generating HCN	Charge sodium cyanide (gram)	Time of estimation	Temperature °F.	HCN-concentration	
					Parts per 100,000 by volume	Percentage of theoretical value
1925—						
February 23 .	11-35 a.m.	0·10	11-50 a.m.	80	65	15
			12-50 p.m.	81	45	10
„ 23 .	1-7 p.m.	0·10				
			1-22 „	81·5	275	36
			2-10 „	81·5	270	32
„ 24 .	..	..	9-0 a.m.	78	185	22
			2-0 p.m.	84	195	23

TABLE XVII.

Multiple-Charge Experiment.

(ii) Loose cotton, air-dry.

Date	Time of generating HCN	Charge sodium cyanide (gram)	Time of estimation	Temperature °F.	HCN-concentration	
					Parts per 100,000 by volume	Percentage of theoretical value
1925—						
April 24 .	2-40 p.m.	0·10				
„ 24 .	..	..	3-0 p.m.	87·5	111	26
„ 24 .	..	..	3-20 „	87·5	105	25
„ 25 .	..	..	10-0 a. m.	87	108	25
„ 25 .	..	..	10-25 „	87	111	26
„ 27 .	..	..	9-10 „	86·5	99	23
„ 27 .	..	..	9-30 „	86·5	108	25
„ 27 .	10-35 a.m.	0·10				
„ 27 .	..	..	11-0 „	87	324	38
„ 28 .	..	..	9-20 „	86	267	31

The above experiments indicate that a charge of 0·10 gram sodium cyanide is approximately sufficient to provide for the superficial saturation of the cotton. The addition of a second charge causes an increase in the concentration of HCN in the desiccator of about 220 parts per 100,000. This amount corresponds approximately with the concentration produced by an initial charge of 0·10 gram in the blank experiments made in the course of this investigation. At the same time it is evident that absorption is not complete with the first charge, because the HCN-concentration gradually decreases after the second charge, especially with the damp cotton. However, 24 hours after the additional charge has been given, the HCN-concentration is still about the value normally obtained with a single charge with no cotton present. It is therefore deduced that under these conditions about 0·10 gram of sodium cyanide is required for the fumigation of 120 grams of cotton, or roughly, about 0·1 per cent. of the weight of cotton. (Compare, however, page 128).

It is noteworthy that the loose cotton gave much the same final result as an equal weight of cotton in bale form tested just previously, the results for which are given in Table XVIII below. It will be observed that the bale took more than three hours to reach the equilibrium condition, while the loose cotton had attained it by the time the first estimation was made: this may be partly accounted for by the fact that the baled cotton had already been fumigated on a previous occasion, although it had subsequently been exposed to the air for a long period before the experiment recorded in Table XVIII.

TABLE XVIII.

Cotton in Bale Form—air-dry, re-fumigated.

Date	Time of generating HCN	Charge sodium cyanide (gram)	Time of estimation	Temperature °F.	HCN-concentration	
					Parts per 100,000 by volume	Percentage of theoretical value
1925—						
April 23 .	10-15 a.m.	0·10				
„ 23 .	..	..	10-45 a.m.	87	147	34
„ 23 .	..	..	11-15 „	87	135	32
„ 23 .	..	..	1-30 p.m.	88	110	26
„ 23 .	..	..	2-0 „	88	102	24
„ 23 .	..	..	3-30 „	87·5	84	20
„ 23 .	..	..	4-0 „	87·5	96	22
„ 24 .	..	..	9-5 a.m.	86	102	24
„ 24 .	..	..	9-50 „	86	111	26

It will be observed that the eight estimations given in this Table (and the first six estimations of the previous Table) really form a series of pairs, the two of a pair having been made immediately after one another. The differences between members of a pair are rather more than were commonly met with in these experiments: the reason for making pairs of determinations was to have mutual checks available. The same procedure was followed generally in subsequent experiments and therefore in the summary tables only the mean values of pairs will be given.

Comparison of the results of Tables XVI and XVII appears to show that there is greater HCN-absorption with the damp cotton than with the air-dry cotton, assuming that in each case the same initial HCN-concentration would have been attained in the absence of the cotton, and that no effect is to be attributed to the damp cotton being baled and the air-dry cotton being in the loose state. Another possible disturbing factor is the difference in temperature, but later experiments indicated that the direct effect of this on absorption was negligible. Still, this temperature difference may have affected the actual amount of HCN generated in the first instance,* and therefore the above evidence that damp cotton is rather more absorptive than air-dry cotton can perhaps hardly be regarded as conclusive. Further results in this connection are discussed on pages 122—28.

(c) *Summary of various Absorption Experiments.* A summary will now be given of various experiments which were made to determine the effects of having the material in baled or loose form, the effect of differences in moisture content of the cotton, the effect of differences in temperature, and the effect of re-fumigation of the cotton. In each of these experiments the charge of sodium cyanide used was 0·10 gram, no water being added: the desiccator throughout was kept immersed in a water-bath of controlled temperature.

*Later tests on this point showed that any such effect was negligible.

TABLE XIX.

Effect of various conditions on absorption of HCN by cotton.

Experiment No.	Material	Date	Time	Temperature °F.	HCN-CONCENTRATION		REMARKS.
					Parts per 100,000 by volume	Percentage of theoretical value	
1	Baled, air-conditioned . .	April 30 Started 11-5 a.m.	11-30 a.m.	86	147	34	The bales were removed after fumigation, exposed to the air overnight and then used for Experiment 2.
			1-30 p.m.	95	159	37	
			3-30 ,,	104	147	34	
2	Baled, air-conditioned. Same as used in Experiment 1.	May 1 Started 9-45 a.m.	10-30 a.m.	88	126	30	The bales were again removed after fumigation, exposed to the air overnight, and then used for Experiment 3.
			12-30 p.m.	95	126	30	
			2-30 ,,	104	124	29	
3	Baled, air-conditioned. Same as used in Experiments 1 and 2.	May 2 Started 9-55 a.m.	10-30 a.m.	88	117	27	
			12-30 p.m.	95	120	28	
			3-30 ,,	104	114	26	
4	Baled, dry. Dried by heating to 100° for 2 hours, then baled, and then further dried by keeping over conc. sulphuric acid for 90 hours.	May 4 Started 10-20 a.m.	11-0 a.m.	89	79	18	The bales were removed after fumigation, exposed to the air for 5 minutes, replaced in desiccator over conc. sulphuric acid for 17 hours, and then used for Experiment 5.
			1-45 p.m.	95	70	16	
			3-45 ,,	104	65	15	
5	Baled, dry. Same as used in Experiment 4.	May 5 Started 10-0 a.m.	10-30 a.m.	88	74	17	
			12-45 p.m.	95	78	18	
			3-45 ,,	104	66	15	
6	Loose, dry. Dried by heating to 100° C. for 3 hours, and then further dried by keeping over conc. sulphuric acid for 68 hours.	May 8 Started 10-10 a.m.	10-30 a.m.	89	100	23	The cotton was removed after fumigation, exposed to the air for 5 minutes, replaced in desiccator over conc. sulphuric acid for 17 hours, and then used for Experiment 7.
			1-45 p.m.	95	90	21	
			3-30 ,,	104	90	21	
7	Loose, dry. Same as used in Experiment 6.	May 9 Started 10-5 a.m.	10-45 a.m.	88	132	31	Moisture content determined after this experiment=3·4 per cent.
			12-45 p.m.	95	127	30	
			2-30 ,,	104	127	30	
8	Baled, damp. Exposed loose to damp atmosphere in water-desiccator for 120 hours before baling.	May 6 Started 10-45 a.m.	11-0 a.m.	89	111	26	The bales were removed after fumigation and kept in the water desiccator overnight.
			1-45 p.m.	95	102	24	
			3-45 ,,	104	90	21	
9	Baled, damp. Same as used in Experiment 8.	May 7 Started 10-0 a.m.	10-45 a.m.	88	126	30	Moisture content determined after this experiment=11·4 per cent.
			1-45 p.m.	95	127	30	
			3-30 ,,	104	117	27	

TABLE XIX—*contd.*

Effect of various conditions on absorption of HCN by cotton—contd.

Experiment No.	Material	Date	Time	Temperature °F.	HCN-CONCENTRATION		REMARKS.
					Parts per 100,000 by volume	Percentage of theoretical value	
10	Loose, damp. Exposed to damp atmosphere in water-desiccator for 114 hours.	May 11 Started 10 a.m.	10-45 a.m.	88	153	36	The cotton was removed after fumigation, kept in the water-desiccator overnight, and then used for Experiment 11.
			1-30 p.m.	95	147	34	
			3-30 „	104	132	31	
11	Loose, damp. Same as used in Experiment 10.	May 12 Started 10 a.m.	10-45 a.m.	88	124	29	The cotton was removed after fumigation, kept in the water-desiccator for 65 hours, and then used for Experiment 12.
			1-45 p.m.	95	112	26	
			3-30 „	118	118	28	
12	Loose, damp. Same as used in Experiments 10, 11.	May 15 Started 10 a.m.	10-45 a.m.	89	159	37	The cotton was removed after fumigation, kept in the water-desiccator overnight, and then used for Experiment 13.
			1-15 p.m.	95	135	32	
			3-45 „	104	..	..	
13	Loose, damp. Same as used in Experiments 10, 11, 12.	May 16 Started 10-5 a.m.	10-45 a.m.	89	132	31	Moisture content determined after this experiment =11·9 per cent.
			1-15 p.m.	95	135	32	
			3-15 „	104	126	30	
14	Blank	April 16	(mean)	87	282	66	
		„ 17	„	87	226	53	
		„ 18	..	87	246	58	
		„ 20	(mean)	87	243	57	
15	Do.	April 21	..	89	240	56	
		„ 22	(mean)	88	187	44	
16	Do.	May 18	12-0 noon	89	213	50	
			2-0 p.m.	95	216	51	
			3-30 „	104	210	49	
17	Do.	May 19	12-30 p.m.	90	198	46	
			3-45 „	88	199	47	
		„ 20	9-30 a.m.	87	177	41	
			12-30 p.m.	87	184	43	

All the experiments in the above Table were carried out with the conditions as far as possible the same in each experiment. It will be observed that of the four different blank experiments two were carried out before the other experiments of this series, and two were carried out after. The results vary somewhat from day to day in any given blank experiment. But for comparison with this series, we are chiefly concerned with the concentration values on the first day only, as in this series each experiment was begun and completed on one day ; the different blank experiments show considerable variation for this initial concentration, the highest value being 282 (experiment 14) and the lowest 198 (experiment 17). It is probable that the first value is unusually high, due possibly to the cyanide of the experiment in question having absorbed a greater percentage of hygroscopic moisture (page 96). Hence it is probably best to assume that the average concentration attained without cotton present would be near the mean of all the observations (29 in number) made in the blank experiments. This mean value is 212. At the same time it has to be recognized that the concentration may not have been higher than that corresponding to the minimum value of about 200 attained in experiment 17.

(*d*) *Discussion of the Results of the Absorption Experiments of Table XIX.*

(i) *Effect of temperature on absorption by cotton.* We may now proceed to the consideration of the results obtained in this series. It may be at once observed that as regards the temperature effect these results do not bear out those obtained in the preliminary experiment. They afford no evidence of any lesser absorption by the cotton as the temperature increased. It may be observed, however, that the period over which the tests extended was only from 4 to 6 hours. Consequently, it might be argued that equilibrium may not have been reached even by the time that the last estimations were made, and that if the temperature-effect were such that the cotton absorbed more HCN at a lower temperature than under the conditions of these experiments (performed with rising temperatures) the temperature-effect might be masked by the time-effect in the attainment of equilibrium in HCN-absorption by the cotton. As against this, we may note that even at the lower temperature considerable HCN-absorption by the cotton has actually occurred, so it appears legitimate to conclude that the temperature-effect cannot at any rate be a large one. This conclusion is strengthened by the fact that it does not involve any assumptions as to what would have been the concentration attained if no cotton had been present. (Compare pages 114, 128.)

(ii) *Effect of re-fumigation.* The effect of re-fumigation may now be considered. Taking all the results together it must be concluded that any irreversible chemical or physical combination is of negligible amount, otherwise succeeding fumigations would be expected to yield a higher atmospheric concentration of HCN, and this is not the case. On the contrary, the treatment given appears to ensure that the cotton gives off all the HCN absorbed, so that it starts *de novo* in each experi-

ment. The variations which occur therefore in successive fumigations of the same sample are probably due in the main to actual differences in the quantity of HCN evolved from the charge.

(iii) *Effect of baling the cotton.* Comparing the cotton in the baled state with that in the loose state, there is no evidence to show that absorption has taken place faster in the latter condition than in the former. In each case equilibrium seems to have been practically established during the quarter of an hour which elapsed between the generation of the HCN and the making of the first estimation. A surprising feature, however, is that the total absorption seems actually to have been greater with the baled cotton than with the loose cotton. Taking the average of the determinations in the different states, we find that in the dry state the baled cotton gives an average atmospheric HCN-concentration of 72 and the loose cotton 111, while in the damp state the baled cotton gives an average atmospheric HCN-concentration of 112, and the loose cotton 135. This deduction differs from that drawn from the preliminary experiments (page 117). It is conceivable that these differences are due to variability of initial concentration, especially in the case of the damp cottons (comparing experiments 9, 11 and 13); but from an examination of the individual results this would hardly appear to be likely in the case of the dry cottons: this case is discussed in greater detail below.

(iv) *Effect of moisture on the HCN-absorption by cotton.* Turning now to the effect of moisture content we are again somewhat confused by the uncertainty about the quantity of HCN generated. The figures just quoted show that for the baled cotton, the average HCN-concentration is 72 for the dry state and 112 for the damp state, while for the loose cotton the average HCN-concentration is 111 for the dry state and 135 for the damp state. It would therefore appear that the cotton is more absorbent of HCN in the dry state than in the damp state.

The conclusions as to the effects of baling and of moisture on the HCN-absorption by cotton were so unexpected that they were closely examined for any possible sources of disturbing effects beyond that due to the unknown initial HCN-concentration. One such possibility lies in the method used for drying the cotton. It is well known that sulphuric acid has a definite vapour pressure[1,2]; the long periods during which the cotton was exposed to the action of the acid vapours thus rendered it possible for the cotton to take up some of the acid by absorption, absorption, or chemical action. The behaviour of such cotton would in any case probably resemble that of a physical mixture so far as its reaction to HCN was concerned. We have already seen how readily sulphuric acid takes up HCN (page 98), so the apparent greater absorption of dry cotton may result simply from its content of sulphuric acid. Some support is lent to this view by the fact that the baled dry cotton apparently absorbs more HCN than the loose dry cotton, and

[1] First Report of the Fabrics Co-ordinating Research Committee, 1925, 47.
[2] Guy Barr. Discussion on Hygrometry, Physical Society, London, 1921, *lxxxi*.

it is also the baled dry cotton which has had the longer primary exposure to the vapour of the sulphuric acid— *viz.*, 90 hours as against 68 hours for the loose cotton. On this view it is possible to understand why the results for the air-conditioned bale of experiments 1-3 gave an average value of 131 for the HCN-concentration as against 72 for the dry state and 112 for the damp state. If we now reject the value for the dry state as suspect, we are left with the result that the damp bale is more absorbent than the air-dry, a conclusion which was not unexpected, and which confirms the result already discussed on page 118.

(e) Experiments with Water present in the Cyanide-Acid Reaction.

The whole question of HCN-absorption by cotton was re-examined at a later date when it was found that the addition of a small amount of water to the charge of cyanide used for generating the HCN made it possible to produce fairly constant initial HCN-concentrations. As before, eight sample bales were made up, each consisting of 60 grams of Texas cotton : four were for use in the dry state and four for use in the wet state. The procedure used in drying the cotton bales was much the same as in the previous experiments, with the important exception that calcium chloride was substituted for sulphuric acid as the drying agent in the desiccator. In view of the possibility of the temperature-effect being complicated by the time-effect of the HCN-absorption by cotton (page 121) other slight modifications were introduced : first, in any one experiment in which the temperature was raised, an estimation of HCN-concentration was made as soon as the bath had been brought to the new and higher temperature ; and secondly, the series of absorption experiments were carried out so that for each experiment in which the temperature was varied a parallel experiment was carried out with the temperature constant. The following Table shows in summary form the experiments carried out and the results obtained therein ; in each experiment the charge was 0·10 gram of sodium cyanide diluted with two drops (0·075 gram) of water.

TABLE XX.

Further Experiments on HCN-Absorption by Cotton, using Watered Cyanide.

Expt. No.	Material.	Date	Time of generating HCN	Time of determination of concentration	Temperature °F	HCN-CONCENTRATION		Remarks
						Parts per 100,000 by volume	Percentage of theoretical value	
18	Baled cotton, dry. Dried by heating to 100° C. for 2 hours and then keeping over calcium chloride till used. (300 hours).	(1926) Mar. 24	9-10 a.m.	9-15 a.m.	80	300	70	Aspiration result = 0·013 gram sodium cyanide per sample bale, *i.e.*, 0·026 gram sodium cyanide for 2 sample bales. Moisture (determined after the experiment = 1·3 per cent.
				9-30 a.m.	80	309	72	
				10-0 a.m.	95	291	68	
				12-0 noon	95	249	59	
				12-15 p.m.	95	252	59	
				1-40 p.m.	104	252	59	
				3-40 p.m.	104	207	48	
				3-50 p.m.	104	204	48	

TABLE XX—*contd.*

Further Experiments on HCN-Absorption by Cotton using Watered Cyanide—contd.

Expt. No.	Material	Date	Time of generating HCN	Time of determination of concentration	Temperature °F	HCN-CONCENTRATION		REMARKS
						Parts per 100,000 by volume	Percentage of theoretical value	
19	Baled cotton, dry. Dried by heating to 100° C. for 2 hours and then keeping over calcium chloride till used. (300 hours).	Mar. 30 .	10-35 a.m.	10-45 a.m.	95	300	70	Aspiration result= 0·008 gram sodium cyanide per sample bale, *i.e.*, 0·016 gram sodium cyanide for 2 sample bales. Moisture (determined after the experiment)=1·4 per cent.
				10-50 a.m.	95	291	68	
				11-55 a.m.	95	276	65	
				12-10 p.m.	95	270	63	
				2-0 p.m.	95	258	60	
				3-0 p.m.	95	219	51	
				3-35 p.m.	95	204	48	
				3-45 p.m.	95	207	48	
20	Baled cotton, damp. Kept in water-desiccator for 600 hours before using.	April 10	9-35 a.m.	9-40 a.m.	82	306	71	Aspiration result= 0·005 gram sodium cyanide per sample bale, *i.e.*, 0·010 gram sodium cyanide for 2 sample bales. Moisture (determined after the experiment) =14·1 per cent.
				9-50 a.m.	82	276	65	
				10-25 a.m.	95	276	65	
				12-25 p.m.	95	234	55	
				12-35 p.m.	95	231	54	
				1-20 p.m.	106	207	48	
				8-15 p.m.	106	180	42	
				3-25 p.m.	106	186	43	
21	Baled cotton, damp. Kept in water-desiccator for 380 hours before using.	April 1	11-0 a.m.	11-5 a.m.	95	294	69	Aspiration result= 0·010 gram sodium cyanide per sample bale, *i.e.*, 0·020 gram sodium cyanide for 2 sample bales. Moisture (determined after the experiment)=12·3 per cent.
				11-20 a.m.	95	258	60	
				12-20 p.m.	95	270	63	
				1-35 p.m.	95	249	58	
				2-35 p.m.	95	189	44	
				3-30 p.m.	95	189	44	
				4-10 p.m.	95	174	41	
				4-20 p.m.	95	171	40	

It was found from experiments 18 to 21 that the rate of absorption was much the same, no matter what the temperature was, and that the rate was faster for damp cotton than for dry. Assuming that the final equilibrium had been practically attained during the 5 hour period of each of these experiments, it appeared that the total absorption also was practically independent of temperature, especially in the case of dry cotton. It was, however, sought definitely to prove this in a new series of multiple-charge experiments (22-27) using watered cyanide charges. (From a practical point of view, it is only necessary to ensure that the HCN-concentration is sufficient to exterminate the weevils. So long as this HCN-concentration is maintained it does not matter whether the final equilibrium between the HCN and the cotton has been attained or not: from a knowledge of the final equilibrium-absorption by cotton, however, it should be possible to assign a higher limit to the quantity of chemicals required for the fumigation.)

The new experiments were carried out as follows. Five crucibles were placed in the desiccator each containing a charge of 0·05 gram sodium cyanide which had been kept dry in a desiccator; a number of charges were given in quick succession (at five-minute intervals), that number being given which it was thought would probably suffice to maintain a concentration of at least 150 parts HCN per 100,000 by volume in the desiccator for 24 hours, even with cotton present. Such conditions would then be analogous to those required in practical fumigation. The desiccator was to be kept at a uniform (room) temperature until equilibrium in the HCN-absorption by the cotton had been established; thereafter the temperature was to be raised to 40° C. (104° F.) and the desiccator kept at this temperature for 4 hours, estimations of the concentration then being taken once more. Equilibrium having been established at the lower temperature, it would then be possible to determine whether the equilibrium remained the same at the higher temperature. For these experiments, however, new supplies of liquid paraffin had to be used, and it was quickly discovered that the new liquid paraffin was more absorbent than that previously used; other liquid paraffin was obtained but this too proved to be slightly absorbent of HCN. As a consequence, the procedure was slightly modified. Experiments were first carried out as already described, but in addition blank experiments were also carried out in exactly similar fashion. Further experiments were also carried out in which the temperature was raised to 40° C. (104° F.) in a number of stages. Experiments were made with dry and damp cottons respectively. These experiments taken in conjunction with the blank experiments made it possible to gauge the actual amount of HCN-absorption by the cotton. The results are given below in Tables XXI and XXII.

TABLE XXI.

The HCN-Absorption of Dried Cotton.

Expt. No.	Material	Date	Time of generating HCN	Time of determination of Concentration	Temperature °F	HCN-CONCENTRATION.		REMARKS
						Parts per 100,000	Percentage of theoretical value	
22	Blank . . .	1927 Jan. 16	3-30 p.m.	3-45 p.m.	77	150	70	Charge of cyanide= 0·05 gram with one drop of water.
				3-55 p.m.	77	150	70	
				8-0 p.m.	75	138	64	
				8-10 p.m.	75	144	67	
		Jan. 17 .	..	9-0 a.m.	72	126	59	
				9-25 a.m.	72	126	59	
				10-30 a.m.	104	144	67	
				10-40 a.m.	104	144	67	
23	Baled cotton, dried. Kept in calcium chloride desiccator till used, (408 hours).	Jan. 13 .	8-50 p.m.	4-10 p.m.	78	228	53	Charges of cyanide= 2 × 0·05 gm.=0·10 gram, with 2 drops of water. Moisture (determined after the experiment)= 4·1 per cent.
				5-0 p.m.	78	228	53	
				8-0 p.m.	77	210	49	
				8-15 p.m.	77	210	49	
		Jan. 14	..	9-0 a.m.	74	150	35	
				9-20 a.m.	74	150	35	
				2-0 p.m.	104	162	38	
				2-15 p.m.	104	168	39	

TABLE XXI—*contd.*

The HCN-Absorption of Dried Cotton—contd.

Expt. No.	Material.	Date.	Time of generating HCN	Time of determination of Concentration.	Temperature °F	HCN-CONCENTRATION. Parts per 100,000	HCN-CONCENTRATION. Percentage of theoretical value	REMARKS
24	Baled cotton, dried. Kept over calcium chloride till used. (72 hours).	Jan. 19 .	11-30 a.m.	11-45 a.m.	77	222	52	Charges of cyanide = 2 × 0·05 gm. = 0·10 gram with 2 drops of water. Moisture (determined after the experiment) = 2·9 per cent.
				4-0 p.m.	76	204	48	
				7-0 p.m.	76	168	39	
		Jan. 20 .	..	7-0 a.m.	76	138	32	
				7-50 a.m.	104	174	41	
				9-0 a.m.	104	162	38	
				10-0 a.m.	104	162	38	
				10-15 a.m.	104	159	37	
25	Blank . . .	Jan. 18 .	11-10 a.m.	11-25 a.m.	77	258	75	Charges of cyanide = 2 × 0·04 gm. = 0·08 gram with 2 drops of water.
				1-0 p.m.	76	246	72	
				4-0 p.m.	75	246	72	
				6-0 p.m.	76	234	68	
		Jan. 19 .	..	7-0 a.m.	75	198	58	
				9-0 a.m.	74	195	57	
				9-35 a.m.	104	264	77	
				10-35 a.m.	104	234	68	

TABLE XXII.

The HCN-Absorption of Damp Cotton.

Expt. No.	Material	Date	Time of generating HCN	Time of determination of Concentration	Temperature °F	HCN-CONCENTRATION. Parts per 100,000	HCN-CONCENTRATION. Percentage of theoretical value	REMARKS
26	Baled cotton, damp. Kept in water-desiccator till used. (384 hours).	(1927) Jan. 12 .	10-5 a.m.	10-30 a.m.	76	246	38	Charges of cyanide = 3 × 0·05 gm. = 0·15 gram with 3 drops of water. Moisture (determined after the experiment) = 12·0 per cent.
				12-0 noon	73	222	34	
				4-0 p.m.	73	204	32	
				8-0 p.m.	73	210	33	
		Jan. 13 .	..	9-0 a.m.	73	204	32	
				9-10 a.m.	73	210	33	
				2-0 p.m.	104	240	37	
				2-20 p.m.	104	240	37	
27	Baled cotton, damp. Kept in water-desiccator till used. (220 hours).	Jan. 20 .	11-30 a.m.	11-45 a.m.	76	318	49	Charges of cyanide = 3 × 0·05 gm. = 0·15 gram with 3 drops of water. Moisture (determined after the experiment) = 11·7 per cent.
				4-0 p.m.	74	258	40	
				7-0 p.m.	74	276	43	
		Jan. 21 .	..	7-5 a.m.	73	228	35	
				8-0 a.m.	77	246	38	
				9-0 a.m.	86	270	41	
				10-0 a.m.	95	282	44	
				11-0 a.m.	104	270	41	

TABLE XXII—*contd.*

The HCN-Absorption of Damp Cotton—contd.

Expt. No.	Material.	Date.	Time of generating HCN	Time of determination of Concentration.	Temperature °F	HCN-CONCENTRATION		REMARKS
						Parts per 100,000	Percentage of theoretical value	
28	Blank . . .	Jan. 21 .	12-5 a.m.	12-20 p.m.	75	264	77	Charges of cyanide = 2×0·04 gm. = 0·08 gram with 2 drops of water.
				4-0 p.m.	74	249	73	
				7-0 p.m.	74	240	70	
		Jan. 22 .	..	7-0 a.m.	73	210	61	
				8-0 a.m.	77	216	63	
				9-0 a.m.	86	243	71	
				10-0 a.m.	95	240	70	
				11-0 a.m.	104	240	70	

It will be observed that different charges were given in the different experiments in order to obtain the result previously mentioned, *viz.*, securing a HCN-concentration next morning of about 150 parts per 100,000. This was fairly successfully achieved, although in some of the experiments the HCN-concentration was rather too high. In view of this inequality of initial charge, the simplest basis of comparison is afforded by the figures showing the percentage attained of the theoretical value. In order to eliminate the effect of absorption of HCN by the liquid paraffin, we may in the first place consider only the HCN-concentrations the next morning. The values for the three blank experiments (Nos. 22, 25, 28) are 59, 58 and 61,—giving an average of 59 per cent. of the theoretical value. For the dried cotton the "next morning HCN-concentration in the desiccator" is $\frac{1}{2}(35+32)=33$ per cent. of the theoretical value, showing that $\frac{26}{59}$ of the charge of cyanide given (0·10 gram) has been used to yield the HCN absorbed by the cotton: *i.e.*, absorption by the cotton (127 grams) accounts for 0·044 gram of sodium cyanide, so that the total HCN-absorption of dried cotton containing 3 to 4 per cent. of moisture requires about 0·035 per cent. of its own weight of sodium cyanide. For damp cotton the "next morning HCN-concentration in the desiccator" is $\frac{1}{2}(33+35)=34$ per cent. of the theoretical value, showing that $\frac{25}{59}$ of the charge of cyanide given (0·15 gram) has been used to yield the HCN-absorbed by the cotton, *i.e.*, absorption by the cotton (127 grams) accounts for 0·068 gram of sodium cyanide, so that the total HCN-absorption of cotton containing about 12 per cent. of moisture requires about 0·05 per cent. of its own weight of sodium cyanide. Thus the amount of sodium cyanide required for very damp cotton is about half as much again as for very dry cotton.

To trace the course of the absorption we may similarly calculate the amount of cyanide necessary to account for the absorption by the cotton at various times after the generation of the HCN. In blank experiments 22, 25, 28 the average HCN-concentration 20 minutes after HCN-generation is 74 per cent. of the theoretical, after the same period the atmospheric HCN-concentration for dried cotton is

52 per cent. and for damp cotton 43 per cent., so that for this period $\frac{2}{7}\frac{2}{4}$ per cent. of the charge (0·10 gram) =0·030 gram sodium cyanide is required for dried cotton and $\frac{3}{7}\frac{1}{4}$ per cent. of the charge (0·15 gram)=0·063 gram sodium cyanide is required for damp cotton. Hence after 20 minutes the dried and damp cotton have absorbed HCN to account for 0·024 per cent. and 0·05 per cent. of their own weight of sodium cyanide respectively. Similar calculations for approximately a 4-hour period yield the result that the dried and damp cotton have absorbed HCN to account for 0·024 per cent. and 0·05 per cent. of their own weight of sodium cyanide respectively.

These results indicate that absorption of HCN by the cotton has been extremely rapid even when allowance is made for the fact that the fresh liquid paraffin introduced for each determination presents a disturbing factor; in the case of the damp cotton, indeed, the final equilibrium appears to have been reached by the time the first determination of HCN-concentration was made. This conclusion does not agree with that drawn from the results of experiments 18-21, Table XX, wherein it appeared that absorption of HCN by cotton was rather slow. However, it may be observed that the HCN-concentration attained after 5 hours is not very different in experiments 18-21, Table XX, from that attained in experiments 22-27, Tables XXI, XXII; so the explanation of the anomaly may simply be that the bales used in the former were more compact than those used in the latter experiments. If this is so, it would appear that the quantity of chemicals required in practical fumigation might be less for heavily compressed bales.

Influence of Temperature. A comparison of experiments 18, 20, with experiments 19, 21 (Table XX) shows that the influence of the temperature upon the rate of absorption of HCN by cotton is negligible. From the results given in Tables XXI, XXII, it appeared at first sight as if the total absorption by the cotton was decidedly less at a higher temperature. The increased atmospheric HCN-concentrations obtained at the higher temperatures were, however, eventually traced to evolution of HCN by the liquid paraffin with rise of temperature, this effect being clearly shown in the blank experiments. When due allowance is made for this effect it is found that the total absorption of HCN by the cotton is in fact practically independent of the temperature within the experimental range 74°—104° F.

Conclusions. We may now sum up the results of the experiments of Tables XX, XXI and XXII in the following conclusions:—

(1) That damp cotton absorbs HCN rather more rapidly than dry cotton;

(2) That damp cotton absorbs HCN to a greater extent than dry cotton, the absorption being possibly 50 per cent. greater for very damp cotton;

(3) That the sodium cyanide required to compensate for the HCN-absorption by the cotton may amount to 0·05 per cent. of the weight of the cotton;

(4) That the influence of temperature upon the absorption of HCN by cotton is negligible within the range 86°—104° F.

2. Intermediate Scale Experiments.

(*a*) *Wooden Chamber Experiments.*

When a bale of cotton was first placed in the wooden chamber it strained the door somewhat, owing to the chamber being slightly too short to accommodate it; some of the cotton was therefore removed from the ends of the bale and the gunny covering replaced. The following result was obtained with the shortened bale :—

Table XXIII.

Date	Time	Parts HCN per 100,000
(1924) April 8	2-35 p.m.	(Experiment Started).
	2-50 p.m.	176
	3-5 p.m.	141
	3-20 p.m.	117
	3-35 p.m.	98
	3-50 p.m.	78
	4-5 p.m.	78

Thus after 1¼ hours' exposure the concentration fell from 176 to 78 parts per 100,000. It appeared, however, as if this fall was partly due to leakage owing to the door having been strained, and consequently no great reliance could be placed upon it. An attempt was made to render the chamber more satisfactory by extending it and trying various devices for making it gas-tight. These did not prove successful. The difficulties were considerably increased later owing to the monsoon rains falling before all the alterations could be completed, and eventually the wooden chamber was abandoned and a new chamber obtained made from steel plates.

(*b*) *Steel-Chamber Experiments.*

By the time the steel-chamber was available, the facts about the lethal HCN-concentration for *Sitophilus oryzae* had been ascertained. Moreover, the full-scale experiment (page 132) had been brought to a successful conclusion and the maximum limit had thus been found for the quantities of chemicals required to maintain the desired HCN-concentration. The present experiments were therefore restricted to an attempt to fix within narrower limits the quantity of cyanide required to maintain a comparatively high HCN-concentration in the presence of a bale of cotton. The results of these experiments are summarized in Table XXIV below.

TABLE XXIV.

Experiments with a Bale of Cotton in the Steel Tank.

Expt. No.	Date	Time	Duration of exposure (hours)	Charges		HCN-concentration		Remarks
				Sodium cyanide	Sulphuric acid	Parts per 100,000 by volume	Percentage of theoretical value	
1	(1925) June 8	2-20 p.m.	Started	4 oz. in 4 oz. water	4 oz. in 4 oz. water	..	..	
		3-0 p.m.	½	..	..	480	17	
		3-45 p.m.	1¼	..	..	490	18	
	June 9	9-30 a.m.	19	..	..	75	3	
		10-30 a.m.	20	..	..	72	3	
	June 10	10-0 a.m.	44	..	..	34	1	
		11-30 a.m.	Second Charge	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		1-0 p.m.	47	..	..	255	6	
		1-30 p.m.	47	..	..	250	6	
	June 11	10-20 a.m.	68	..	..	84	2	
		1-0 p.m.	71	..	..	74	2	
		3-30 p.m.	73	..	..	53	1	
	June 12	10-0 a.m.	96	..	..	58	1	
		11-30 a.m.	97	..	..	31	..	The tank was opened on June 12th at 12-30 p.m. and the fan run to drive out the air surrounding the bale. At 1-55 p.m. the tank was closed again, and estimations made of HCN-concentration to determine the extent to which the HCN was given up by the bale of cotton.
		2-15 p.m.	..	..	..	20	..	
		3-15 p.m.	1	..	..	22	..	
		4-15 p.m.	2	..	..	20	..	
	June 13	9-15 a.m.	21	..	..	33	..	
		10-15 a.m.	22	..	..	34	..	
		11-15 a.m.	23	..	..	35	..	
		12-15 p.m.	24	..	..	35	..	
	June 15	9-25 a.m.	45	..	..	27	..	
2	June 18	2-30 p.m.	Started	6 oz. in 6 oz. water	6 oz. in 6 oz. water	..	..	Experiment 2 was carried out on the same bale as Experiment 1. As in Experiment 1, estimations were made of the rate and extent to which the bale gave off HCN, with much the same results. Determinations were afterwards made of the moisture content of the cotton and jute of the bale. Moisture content of cotton = 9·0 per cent. Moisture content of jute = 8·3 per cent.
		3-0 p.m.	½	..	..	915	22	
		3-15 p.m.	¾	..	..	920	22	
		4-0 p.m.	1½	..	..	704	17	
	June 19	9-30 a.m.	19	..	..	183	4	
		11-20 a.m.	21	..	..	182	4	
		1-50 p.m.	23	..	..	170	4	
		4-15 p.m.	26	..	..	163	4	
	June 20	9-30 a.m.	43	..	..	124	3	
		9-30 a.m.	91	..	..	68	2	
3	Jun 26	10-35 a.m.	Started	4 oz. in 4 oz. water	4 oz. in 4 oz. water	..	..	Final moisture content of cotton = 10·9 per cent.
		11-0 a.m.	½	..	..	490	18	
		2-0 p.m.	3½	..	..	430	15	
	June 27	9-20 a.m.	22	..	..	134	5	
	June 29	9-15 a.m.	47	..	..	82	3	
	June 30	9-10 a.m.	71	..	..	72	3	

TABLE XXIV—*contd.*

Experiments with a Bale of Cotton in the Steel Tank—contd.

Expt. No.	Date	Time	Duration of exposure (hours)	Charges		HCN-concentration		Remarks
				Sodium cyanide	Sulphuric acid	Parts per 100,000 by volume	Percentage of theoretical value	
4	July 2	11-15 a.m.	Started	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	Initial moisture content of cotton = 10·2 per cent.
		11-40 a.m.	½	..	..	264	19	
		2-0 p.m.	3	..	..	190	14	
		4-0 p.m.	5	..	..	180	13	
	July 3	10-0 a.m.	23	..	..	85	6	
	July 4	9-20 a.m.	46	..	..	31	2	
5	July 9	9-50 a.m.	Started	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		10-15 a.m.	½	..	..	288	21	
		1-35 p.m.	4	..	..	146	11	
		2-45 p.m.	Second Charge	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		3-20 p.m.	5½	..	..	422	15	
	July 10	9-15 a.m.	23	..	..	156	6	
	July 10	12-15 p.m.	Third Charge	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		12-30 p.m.	27	..	..	400	10	
		1-35 p.m.	28	..	..	322	8	
		2-35 p.m.	29	..	..	292	7	
		3-35 p.m.	30	..	..	260	6	
		4-30 p.m.	31	..	..	250	6	
	July 11	9-0 a.m.	47	..	..	180	4	
		11-0 a.m.	49	..	..	174	4	
	July 12	9-20 a.m.	72	..	..	82	2	
6	July 14	9-30 a.m.	Started	2 oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		10-0 a.m.		..	..	304	22	
		11-0 a.m.		..	..	254	18	
		12-0 noon		..	..	208	15	
		1-30 p.m.		..	..	138	10	
		2-30 p.m.	Second Charge	oz. in 2 oz. water	2 oz. in 2 oz. water	..	..	
		3-0 p.m.	5½	..	..	410	15	
		4-0 p.m.	6½	..	..	362	13	
	July 15	9-20 a.m.	24	..	..	190	7	
7	July 17	10-30 a.m.	Started	4 oz. in 4 oz. water	4 oz. in 4 oz. water	..	..	
		11-0 a.m.	½	..	..	668	25	
		12-0 noon	1½	..	..	466	17	
		1-30 p.m.	3	..	..	366	13	
		2-30 p.m.	4	..	..	318	11	
		3-30 p.m.	5	..	..	292	11	
		4-30 p.m.	6	..	..	260	9	
	July 18	9-10 a.m.	23	..	..	152	5	
		10-10 a.m.	24	..	..	144	5	
		11-10 a.m.	25	..	..	142	5	
		12-10 p.m.	26	..	..	142	5	

In connection with the above experiments, it has to be observed that all except the first are re-fumigation experiments. Consequently, if there were any irreversible change, one would expect that in the experiments subsequent to the first less absorption would occur. On the other hand, when a bale has been subjected to long-period fumigation, HCN will have penetrated to some depth in the bale, and on exposure to the air it may take a considerable time for this HCN to escape. When the bale is re-fumigated, therefore, the loss of HCN absorbed in the previous fumigation may not have been completed and for this reason a lesser absorption may occur. In any case the above results do point to a diminished absorption on re-fumigation. It is clear from experiments 4, 5 and 6 that a charge of 2 oz. of cyanide is far too small to maintain for 24 hours a minimum concentration of 150 parts HCN per 100,000. From experiments 1, 3 and 7, it would appear that a single charge of 4 oz. of cyanide is also insufficient to maintain this minimum concentration for 24 hours, although in the last experiment No. 7, this charge appeared to be nearly sufficient. From experiments 5 and 6, it would appear, ignoring the above-mentioned possible effects in re-fumigation, that the method of using 4 oz. cyanide in successive charges of 2 oz. each at suitable intervals would just be sufficient to maintain the desired HCN-concentration. Alternatively, a single charge of rather less than 6 ozs. cyanide, as used in experiment 2, would appear to be necessary. From the blank experiments (page 101) it would appear that about half an ounce of this cyanide is used in producing the desired minimum concentration in the free space of the steel chamber.

It will be observed that in all these experiments the moisture content was high. The bale when first received was very damp and had to be allowed to condition for some days before use, but as the monsoon had set in it was not possible to get the bale into as dry a condition as desired. Moreover, the bale was very bulky, having evidently been lightly pressed. In these circumstances absorption was likely to have been on the high side.

Conclusion. The final conclusion drawn from these experiments was that when allowance was made for the fact that the tank was much more gastight than barges were likely to be, it would be necessary to allow for the use on a practical scale, under similar conditions, of one pound weight of sodium cyanide for every three bales of cotton which had to be fumigated, the total weight of cyanide being added in successive charges at suitable intervals. (Compare, however, pages 141-43).

3. Full-scale Experiments.

The first barge experiment was carried out on April 3-4, 1924. In the hold 79 bales of American cotton were arranged in three layers, the layers being separated by battens so as to leave plenty of free space for the circulation of the air. The fumigation outlet tube with its branches was laid out so as to ensure that a fairly even distribution of HCN throughout the hold should rapidly be attained. Test tubings were arranged for taking samples of the atmosphere within the hold at five

different points—the four corners and the centre. Small tins with copper gauze lids, (as described on page 84), each containing 20 grain-weevils, were placed among the bales at various points and levels. After generating the HCN, however, it was found that the concentration attained was very low, and about 4½ hours after the HCN had been generated from 3 lb. of sodium cyanide, the concentration was only 15 parts per 100,000, *i.e.*, only about 2 per cent. of the theoretical value. It was recognized that these low figures might be due to absorption of the HCN by the cotton bales, but as some preliminary laboratory experiments had given no evidence that the absorption might be so great, the result was attributed to an unsatisfactory hatch cover. When this cover was held up to the light, large numbers of pin-holes were discernible between the threads; it was therefore concluded that these afforded a ready means of escape to the HCN.

As a result of this experiment, a new hatch cover was obtained consisting of parallel doubled two-ply rubbered balloon fabric, aluminium-coated externally and having two layers of rubber, one internal and one between the plies of fabric. A repetition of the experiments with the new hatch cover proved quite successful. Some preliminary tests made with cotton absent showed that under these conditions the leakage over a comparatively long period had been reduced to satisfactory dimensions. The fumigation of cotton bales was therefore proceeded with. The same hold of the barge used in the first experiments was filled with 70 bales of American cotton, arranged as before in three layers separated by battens. The results obtained are summarized in the following Table.

TABLE XXV.

Day	Cotton present or absent	Charges of sodium cyanide added during the day	Total weight of sodium cyanide added during the day	Cumulative weight of sodium cyanide added without opening up	Maximum concentration of HCN recorded during the day		Concentration of HCN the next morning	
					Parts per 100,000	Percentage of theoretical value	Parts per 100,000	Percentage of theoretical value
			lb.	lb.				
1	Absent	2 of 1·5 lb	3	3	208	28	102	14
2	Do	1 of 2·5 lb	2·5	2·5	157	26	57	9
3	Present	1 of 1·5 lb	2·5	2·5	75	12	5	1
4	Absent	1 of 2 lb	..	..	..	..	..	..
		1 of 1 lb	3	3	186	25	82	11
5	..	1 of 2 lb	2	5	206	17	95	8
6	Present	2 of 2 lb	..	..	..	..	..	..
		1 of 3 lb	7	7	202	12	18	1
7	Do	3 of 2 lb	6	13	138		37	1
8	Do	3 of 2 lb	6	19	159	3	53	1
9	Do	4 of 2 lb	8	27	221	3	106	2

Where a horizontal line is drawn in the above table, it indicates that the hold was opened up between the experiments on the days concerned.

Grain-weevils present in the first and last experiments were all killed in each case.

The results obtained in the experiments with cotton present can only be explained on the view that HCN is being absorbed by the cotton bales. From the figures for concentration of gas on days 6 to 9, it is clear that the method of giving cumulative charges has by the 9th day caused the cotton to approach its maximum absorptive capacity. This is shown by the fall in the HCN-concentration—from the maximum (221) on the ninth day to 106 the next morning—being very similar to the falls experienced when cotton was absent. The progressive increase in HCN-concentration recorded each morning from the 7th to 10th days, as shown in column 7, can also only be satisfactorily explained on the hypothesis that absorption by the cotton bales is taking place. Experiments made in discharging the gas from the barge on the 10th and subsequent days confirmed this view. For after the hatch cover had been removed at one corner, the machine was run for 3 hours (without any charge of cyanide) so as to drive out the gas. The hold was closed again and determinations were made of the HCN-concentration. This was found to be about 25 parts per 100,000, the cotton having evidently given up some of the gas previously absorbed. This gas was again removed, and the operation on repetition yielded much the same result, the values for the HCN-concentration gradually rising from 10 to 21 parts per 100,000. Again the hold was opened, the fan run, and the hold closed for the night. Determinations of the HCN-concentration next morning indicated a concentration of 31 parts per 100,000. Later, the whole cover was completely removed, the engine kept running, and after one hour had elapsed determinations of HCN-concentration gave a value of only 2 parts per 100,000. These later experimental results show that when the atmosphere surrounding the cotton bales was rendered free of HCN, the cotton gave up some of the gas which it had absorbed, this process going on repeatedly when the HCN evolved was continuously removed. It will be observed that in the final experiment 27 lb. of cyanide were used in all for the 70 bales of cotton, *i.e.*, 1 lb. of cyanide for about 2·5 bales. As this experiment lasted for 4 days, however, and leakage and absorption will have been going on continuously, it is evident that if the whole charge had been given at intervals during a single day, a less weight would have been required to maintain the atmospheric HCN-concentration for the 24 hours only. In these circumstances it appears probable that the charge needed would not exceed 1 lb. of cyanide for every three bales of cotton, and might be considerably less.

From this experiment the following are the chief conclusions which were drawn :—

(1) That, as already stated, fumigation can be successfully carried out in a barge.

(2) That a comparatively large amount of chemicals (one pound weight of cyanide for every three bales of cotton) is necessary to produce a lethal

concentration of HCN because of the absorption of this gas by the cotton bales.

(3) That the removal of the HCN absorbed by the cotton presents no difficulty.

The successful issue of this experiment, combined with other results previously described, led the Government of India to issue a Notification under the Destructive Insects and Pests Act, 1914, prohibiting the importation of American cotton into India without fumigation with HCN, and confining such importation to the port of Bombay. The Notification in question is reproduced as Appendix V to this memoir.

4. General Conclusions on Cotton Absorption Experiments.

(1) That cotton does absorb HCN, whether the cotton be loose or baled, dry or damp.

(2) That damp cotton is rather more absorbent than dry cotton, the difference in absorption for extremes of humidity being about 50 per cent. of the dry absorption (pages 118, 122-28).

(3) That within the limits of temperature 86°—104° F. the actual temperature has very little influence on the rate or on the degree of absorption of HCN by cotton (pages 114, 121, 128).

(4) That absorbed HCN is desorbed fairly rapidly and completely, and that any irreversible chemical combination which may occur takes place only to a negligible extent (pages 121-22, 132, 134).

(5) That the degree of compression attained for the small experimental bales is insufficient to reveal whether the degree of compression of the cotton makes any appreciable difference either to the rate of absorption or to the final equilibrium (pages 110, 117, 122-23).

(6) That with dry charges of sodium cyanide the amount of cyanide required for satisfactory fumigation (*i.e.*, to ensure killing the grain-weevil) is about 0·10 per cent. of the weight of cotton (page 116) but that with water present in the cyanide-acid reaction about half this quantity, 0·05 per cent. of the weight of the cotton, is sufficient. This is an estimate from the small-scale experiments only (page 128). In either case the requirement of sodium cyanide corresponds to an absorption of HCN up to about 0·02 per cent. of the weight of the cotton at the given atmospheric concentration of 150 parts HCN per 100,000 air. With a bale of cotton, in a damp condition and fumigated in a chamber which leaks to some extent, the weight of sodium cyanide required is about 0·07 per cent. of the weight of the cotton bale or one pound weight of sodium cyanide for three bales of cotton (page 132). In a barge, where leakage is greater than in the single bale experiments, the weight of sodium cyanide required—when added during a period of 4 days—is about 0·08 per cent. of the weight of the cotton bales (page 134). From all these results, it was finally concluded that with charges given frequently the weight of sodium cyanide required for satisfactory fumigation on a practical scale should not exceed 0·07

per cent. of the weight of the cotton, or one pound weight of sodium cyanide for three bales of cotton. This is in addition to the sodium cyanide required for producing the desired HCN-concentration in the free space present. Subsequent experience on a practical scale, however, has shown that one pound weight of sodium cyanide is sufficient for the satisfactory fumigation of about five bales of cotton when good barges are used and when the bales are both dry and also highly-compressed (compare page 143).

(7) That fumigation with HCN can be satisfactorily carried out on a large scale in barges (page 134).

VII. Small-Scale Absorption Experiments with Jute.

The experiments with jute were carried out on the small-scale only. They comprised :—

(1) Experiments with baled jute ;
(2) Experiments with jute having different moisture contents ;
(3) Experiments at different temperatures ;
(4) Aspiration experiments.

(*a*) General.

These experiments were carried out in precisely the same manner as already described in the case of the cotton experiments, two small bales of jute hessian each weighing 60 grams being used. The first experiments showed at once that the absorption by the jute was considerable, thus :—

TABLE XXVI.

Fumigation of Small Jute Bales.

Expt. No.	Date	Time of generating HCN	Charge (air-dry) sodium cyanide (gram)	Time of estimation	Temperature ° F	HCN-concentration	
						Parts per 100,000 by volume	Percentage of theoretical value
1	(1925) June 17	2-45 p.m.	0·05	3-5 p.m.	86	30	14
				3-25 p.m.	86	*nil*	..
		3-40 p.m.	0·05	4-0 p.m.	86	63	17
	June 18	..	..	9-15 a.m.	85	33	5
	June 19	..	..	9-40 a.m.	85	30	7
	June 20	..	..	10-10 a.m.	84	33	8
2	June 25	2-0 p.m.	0·10	2-20 p.m.	84	66	15
	June 26	2-50 p.m.	0·10	3-10 p.m.	83	162	10
				9-30 a.m.	83	126	15
3	July 7	10-45 a.m.	0·10	11-5 a.m.	82	90	21
				1-30 p.m.	83	30	7
		2-0 p.m.	0·10	2-20 p.m.	84	180	21
				4-0 p.m	84	150	18
	July 8	..	..	10-0 a.m.	86	72	8

TABLE XXVI—*contd.*

Fumigation of Small Jute Bales—contd.

Expt. No.	Date.	Time of generating HCN	Charge (air-dry) sodium cyanide (gram)	Time of estimation	Temperature °F	HCN-CONCENTRATION	
						Parts per 100,000 by volume	Percentage of theoretical value
4	July 16 .	9-10 a.m.	0·10	9-20 a.m.	83	105	25
				10-20 a.m.	83	50	12
		11-0 a.m.	0·10	11-15 a.m.	83	195	23
				12-15 p.m.	83	160	19
	July 17 .	..	..	9-15 a.m.	83	110	13

In connection with experiment 2 above, aspiration experiments were carried out : after drawing through 84 litres of air, the amount of HCN recovered was equivalent to 0·018 gram sodium cyanide, while the concentration of HCN remaining in the fumigation desiccator accounted for 0·028 gram sodium cyanide, making a total of 0·046 gram sodium cyanide out of the 0·20 gram sodium cyanide actually used, thus leaving 77 per cent. of the cyanide unaccounted for. Hence this aspiration result appeared to be as unsatisfactory as those obtained with cotton.

In order to determine whether the aspiration result might be partly due to irreversible chemical combination of the HCN with the jute, some re-fumigation experiments were carried out. These gave the following results :—

TABLE XXVII.

Re-fumigation Experiments on a Small Jute Bale.

Expt. No.	Date	Time of generating HCN	Charge (air-dry) sodium cyanide (gram)	Time of estimation	Temperature °F	HCN-CONCENTRATION		REMARKS
						Parts per 100,000 by volume	Percentage of theoretical value	
5	(1925) July 20	10-35 a.m.	0·10	10-45 a.m.	83	120	28	The bale was removed after fumigation, exposed to the air overnight and then used for Experiment 6.
				11-45 a.m.	83	100	23	
				1-45 p.m.	84	107	25	
				3-25 p.m.	84	110	26	
				9-45 a.m.	83	60	14	
	July 21	..	..	10-45 a.m.	84	67	15	
6	July 22	10-5 a.m.	0·10	10-15 a.m.	84	125	29	The bale was removed after fumigation, exposed to the air overnight and then used for Experiment 7.
				11-15 a.m.	84	105	25	
				12-15 p.m.	83	92	22	
				2-15 p.m.	84	102	24	
				4-15 p.m.	83	96	22	
	July 23	..	..	9-30 a.m.	83	45	11	
7	July 24	10-20 a.m.	0·10	10-30 a.m.	83	125	29	
				11-30 a.m.	83	110	26	
				12-30 p.m.	84	105	25	
				2-30 p.m.	84	95	22	
				4-30 p.m.	84	102	24	
	July 25	..	..	10-0 a.m.	83	66	15	

Making due allowance for the fact that the above results were obtained using a single small bale of jute while the results of experiments 1-4 relate to two such bales in each case, we see that the progress of absorption is much the same in both sets of experiments. This points to the absence to any large extent of irreversible chemical charge. The conclusion must therefore be drawn that the process is chiefly a reversible one—whether chemical or physical—and that the HCN which is absorbed in the fumigation desiccator is desorbed on exposure to air.

Considering now Tables XXVI and XXVII together, we see that the absorption capacity of jute is much greater than that of cotton (compare Tables XVI—XIX). From experiment 1 it appears that absorption by the 120 grams jute is complete within 18 hours when a charge of 0·10 gram of cyanide (air-dry) is used ; and that this charge gives a final HCN-concentration of about 30 parts per 100,000, instead of about 212 parts per 100,000 usually obtained with this charge (page 121). With a total charge 0·20 gram cyanide (air-dry) as used in experiments 2, 3 and 4, the HCN-concentration varied somewhat, being 126 parts per 100,000 after 19 hours (experiment 2), 72 parts per 100,000 after 23 hours (experiment 3), and 110 parts per 100,000 after 24 hours (experiment 4). If we assume that equilibrium had been reached in each case, we have the result, striking a rough average, that the HCN-concentration in the desiccator is only 103 parts per 100,000 instead of 424 parts per 100,000 which would have been expected in blank experiments from the total of two charges of 0·10 gram each. To ensure a higher HCN-concentration in the desiccator even more than 0·20 gram cyanide would be needed, say 0·30 gram of cyanide (air-dry), of which about 0·10 gram would be needed for the desired HCN-concentration in the air in the desiccator, while 0·20 gram would be needed for HCN absorbed by the jute. In other words, when calculating the weight of cyanide required for saturating the jute at the given HCN-concentration, we must allow for an amount of sodium cyanide equal to 0·17 or say 0·2 per cent. of the weight of jute present. This, of course, is with no water present in the cyanide-acid reaction. The results obtained with water present are discussed on pages 139-141.

(*b*) Experiments with Samples of Jute having different Moisture Contents.

These experiments were made after it had been found how large a difference in the concentration of HCN was caused by adding two drops (0·075 gram) of water to each charge of sodium cyanide (0·10 gram) before adding the acid. The same charge was given in each experiment. Jute hessian from a cotton bale was used for the experiments : the damp jute was prepared by keeping in a " water-desiccator " and the dry jute by keeping in a " calcium-chloride desiccator " before the respective experiments. One pair of dry bales and one pair of damp bales were used in successive experiments first at a constant temperature and afterwards at

different temperatures. The results are given in Tables XXVIII and XXIX below :—

Table XXVIII.

Absorption Experiments with Jute at Constant Temperature (95°F.).

Expt. No.	Material	Date	Time of generating HCN	Time of estimation of concentration	HCN-concentration		Remarks
					Parts per 100,000	Percentage of theoretical value	
1	Jute, dry	(1926) Mar. 12	10-0 a.m.	10-10 a.m.	246	58	Moisture content= 3·3 per cent. Aspiration result = 0·024 gram sodium cyanide per bale, *i.e.*, 0·048 gram sodium cyanide for 2 bales. Sodium cyanide unchanged *nil*.
				10-25 a.m.	231	54	
				11-15 a.m.	183	43	
				12-15 p.m.	156	37	
				1-37 p.m.	144	34	
				2-30 p.m.	129	30	
				3-30 p.m.	132	31	
2	Jute, damp	Mar. 15	10-35 a.m.	10-40 a.m.	219	51	Moisture content= 23·0 per cent. Aspiration result= 0·016 gram sodium cyanide per bale, *i.e.*, 0·032 gram for 2 bales. Sodium cyanide unchanged =0·002 gram.
				10-50 a.m.	195	46	
				11-30 a.m.	135	32	
				12-15 p.m.	135	32	
				1-35 p.m.	126	30	
				2-30 p.m.	123	29	
				3-30 p.m.	102	24	
				3-45 p.m.	105	25	

The above experiments indicate that very damp jute absorbs HCN to a slightly greater extent than very dry jute. The effect of moisture is, however, very small compared with the large total absorption. This is confirmed by the results obtained in the experiments where the temperature was raised in stages during the fumigation (Table XXIX).

Table XXIX.

Absorption Experiments with Jute at Different Temperatures.

These experiments were carried out on the same lines as the previous experiments, the charge of sodium cyanide used in each experiment being 0·10 gram with two drops of water.

Expt. No.	Material	Date	Time of generating HCN	Time of determining concentration	Temperature °F.	HCN-concentration		Remarks
						Parts per 100,000 by volume	Percentage of theoretical value	
1	Jute, dry	(1926) Mar. 8	11-20 a.m.	11-30 a.m.	81	213	50	Moisture content= 2·1 per cent. Aspiration result= 0·019 gram sodium cyanide per bale, *i.e.*, 0·038 gram sodium cyanide for 2 sample bales.
				2-40 p.m.	95	159	37	
				3-45 p.m.	104	132	31	
		Mar. 9		10-40 a.m.	79	67	16	

TABLE XXIX—*contd.*

Absorption Experiments with Jute at Different Temperatures—contd.

Expt. No.	Material.	Date.	Time of generating HCN	Time of determining concentration.	Temperature °F	HCN-CONCENTRATION		REMARKS.
						Parts per 100,000 by volume	Percentage of theoretical value	
2	Jute, dry	Mar. 18	9-10 a.m.	9-25 a.m. 12-15 p.m. 3-45 p.m.	79 95 104	260 150 127	61 35 30	Moisture content = 3·2 per cent. Aspiration result = 0·018 gram sodium cyanide per sample bale, *i.e.*, 0·036 gram sodium cyanide for 2 sample bales. Sodium cyanide unchanged = 0·005 gram.
3	Jute, damp	Mar. 10	9-20 a.m.	9-30 a.m. 12-15 p.m. 3-45 p.m.	80 95 104	166 133 118	39 31 28	Moisture content = 23·1 per cent. Aspiration result = 0·014 gram sodium cyanide per sample bale, *i.e.*, 0·028 gram sodium cyanide for 2 sample bales. Sodium cyanide unchanged = 0·001 gram.

The aspiration results are again unsatisfactory, and again from one-half to two-thirds of the charge of sodium cyanide is left unaccounted for.

When these results are compared with those previously described, it is evident that the most striking feature is the high absorptive capacity of the jute. After 5—6 hours' exposure in the fumigation desiccator, the concentration of HCN is much the same whether the bales have been kept at a uniform temperature or the temperature has been varied, nor does the moisture content of the jute make any appreciable difference. It may be observed that a much longer time is taken by the jute to reach a condition of equilibrium than is taken by cotton (compare page 128). From the results of the blank experiments discussed on page 98 it is clear that, in the absence of the jute, the HCN-concentration from 0·10 gram sodium cyanide would have been about 312 parts per 100,000. From the values of HCN-concentration given above, it appears that the 120 grams of jute, dry or damp, absorb in 6 hours about 60 per cent. of the HCN generated from the 0·10 gram charge of sodium cyanide. Assuming that equilibrium had been attained in experiment 1, Table XXIX, by the time 24 hours had elapsed, it appears that of the 0·10 gram sodium cyanide used, about 20 per cent. is required to account for the HCN-concentration in the desiccator, leaving 80 per cent. to be accounted for by HCN-absorption by the jute. In this case, however, the final atmospheric HCN-concen-

67 parts per 100,000 and is therefore well below the desired minimum of 150 parts per 100,000. To ensure the latter concentration being attained it appears probable that the amount of sodium cyanide required will not be less than 0·10 per cent. of the weight of the jute.

(c) Conclusions.

The following are the chief conclusions which may be drawn from this section :—

(1) That jute has a higher and more rapid absorptive power than cotton for HCN, absorbing about 0·04 per cent. of its own weight of HCN at an atmospheric HCN-concentration of 150 parts HCN per 100,000 air.

(2) That the absorptive power of jute is only to a small extent dependent on its moisture content, being however slightly greater for damp jute than for dry (page 139).

(3) That the absorptive power of jute remains practically unchanged throughout the temperature range 86°—104° F. (pages 139—40).

(4) That for the saturation of jute with HCN in an atmosphere containing 150 parts HCN per 100,000, the amount of sodium cyanide required is about 0·10 per cent. of the weight of the jute (above).

VIII. General Discussion of Results : Practical Considerations.

Although the results obtained have already been discussed in detail in connection with each experiment separately, it is convenient here to discuss the various results in relation to one another, and to the general question as to what constitutes " satisfactory fumigation " on a practical scale.

In the first place, the conclusion has been reached (pages 104, 106, 109) that under Bombay conditions the exposure of the grain-weevils or the boll-weevils to a HCN-concentration of 150 parts per 100,000 (by volume) for 20 hours will be sufficient to kill them. Alternatively, an exposure for 4 hours to a HCN-concentration of 450 parts per 100,000 will also be sufficient to kill the boll-weevil (page 109).

The conclusion was reached in connection with the cotton absorption experiments that the weight of sodium cyanide required for the saturation of the cotton alone is about 0·05 per cent. of the weight of the cotton (page 128). In connection with the jute experiments the conclusion was reached that for the saturation of the jute the amount of sodium cyanide required is about 0·10 per cent. of the weight of the jute (page 140). The amounts required are rather greater under damp conditions than under dry conditions, but the conditions of temperature may be ignored so far as the HCN-absorption is concerned. Considering 100 cotton bales of standard weight (500 lb.) with standard tare (20 lb.) we have to allow for a weight of 48,000 lb. of cotton and 2,000 lb. of jute. With the percentage requirements of sodium cyanide referred to above, it follows that for 100 bales of cotton the sodium

cyanide required is 24 lb. for the cotton and 2 lb. for the jute, making 26 lb. in all. Evidently, although the jute is much more absorbent of HCN than the cotton, the comparatively small amount of jute present makes it of practically negligible account when calculating the quantity of sodium cyanide required for fumigation purposes. Thus we may conclude that the quantity of sodium cyanide required to saturate the cotton bales to the desired concentration is about 0·05 per cent. of the weight of the bales, or about one pound weight of cyanide to every four bales of cotton.

It is important to observe that in calculating the total weight of cyanide required due allowance must be made for the amount required to give the desired HCN-concentration in the free space, *i.e.*, space not occupied by the cotton.

On the large scale a further difficulty is encountered that a gradual fall in HCN-concentration cannot be entirely prevented even when no cotton is present, owing to the impossibility of preventing some leakage. This fact entails the practical consequence that a greater charge of cyanide must be given than that calculated simply from the weight of the cotton bales. Thus from the steel chamber experiments it was concluded (page 132) that one pound of sodium cyanide would be sufficient for only three bales of cotton, while from the barge experiment it appeared that one pound of sodium cyanide was sufficient for only 2·5 bales of cotton (page 134). In these experiments it may be noted that the final HCN-concentration was below that of 150 parts per 100,000 which was found to be desirable for a 20 hours' exposure.

Another point which has to be considered is the actual period during which the weevils are exposed to the desired HCN-concentration. If the HCN-concentration in the barge were maintained uniformly at 150 parts per 100,000, it is evident that the jute covering and the cotton just below it would for a period experience a less HCN-concentration than the normal, because while the jute is actually absorbing HCN at the commencement of fumigation there must be a fall in HCN-concentration in the immediate vicinity. Now it is on the underside of the jute covering where boll-weevils may be expected to occur; indeed, one such weevil has in fact been found in this very position. Such weevils would therefore be screened for a time by the more absorbent jute covering. However, the HCN would gradually pass inwards because the outer layers would act as carriers of the HCN, continuously absorbing it on the high HCN-concentration side and desorbing it on the low HCN-concentration side. A stage would no doubt be reached very quickly when the jute covering and the outer cotton would be practically saturated with HCN, and from this time onward the HCN-concentration in the interstices of the outer cotton would be much the same as that in the air spaces of the barge. Hence, in view also of the fact that with the Liston Cyanide Fumgiator the air is kept in constant circulation, it is legitimate to suppose that the effect referred to is of small dimensions only.

However, it is no doubt best to make provision for this effect. It has already been pointed out that fumigation at an actual HCN-concentration of 450 parts per

100,000 appears to be effective in 4 hours. With uncertainty prevailing as to the time needed for the saturation with HCN of the jute covering and the outer layers of cotton, there is considerable advantage in using a long-period fumigation at a comparatively low HCN-concentration instead of a short-period fumigation at a high HCN-concentration. It is better still, however, to combine the advantages of both methods. In actual practice this is in fact attempted. Fumigation is carried on over a period of approximately 20 hours : it is begun early on one morning and finished the following morning. During the day large charges of HCN are generated at short intervals, so that a very high concentration is maintained throughout the day. When the barge is left for the night the HCN-concentration must not be lower than 200 parts per 100,000. In deciding on the charge to be given before the barge is left for the night due regard is paid to the rate of fall of concentration experienced just previously.

Some idea of the concentrations attained and the method of giving the charges in practical working is conveyed by the abstract Tables which form Appendix IV. This is given in two parts : Table I gives some typical results obtained during the monsoon, while Table II gives typical results obtained after the monsoon. It is at once evident that more sodium cyanide is required during the monsoon, no doubt on account of the greater absorption by the cotton which then takes place. It is, moreover, a remarkable fact that less cyanide is needed for the fumigation than was anticipated from many of the experiments described in the foregoing pages. Reference to Appendix IV will show, however, that in the majority of cases the " next morning HCN-concentration" has not in fact been as high as 150 parts per 100,000. An exception exists in the case of Barge No. 13 fumigated on August 26, 1926 and September 1, 1926. This, however, was a barge which leaked only to a very slight extent ; furthermore, the consumption of cyanide in the first case was actually 1 lb. for 3·3 bales,—not very different from the figure previously deduced. In the second case one pound of cyanide was required for 4·7 bales, but here the fumigation did not extend over the full 24-hour period. On the whole, therefore, the monsoon results confirm the results of the steel tank experiments, which were also carried out in the monsoon.

The post-monsoon results, as previously pointed out, show that less cyanide is needed under these conditions. This is, of course, due to the fact that dry cotton does not absorb so much HCN as damp cotton. Considering only the results where the "next-morning concentration" was up to standard, we see that with Barge No. 8 on November 8, 1926, and on November 29, 1926, together with Barge No. 23 on November 24, 1926, and with Barge No. 30 on November 30, 1926, one pound of cyanide under post-monsoon conditions and with good barges will suffice for about 5·5 bales of cotton.

It should be observed, however, that the cotton in these barges was very highly compressed (about 40 lb. per cubic foot) and therefore very different from the bales on which the experiments had been carried out. From these results the deduction

is therefore drawn that when the bales being fumigated are highly compressed, the requirement of cyanide is decidedly less.

IX. Conclusions.

The conclusions which may be drawn from the various experiments are as follow :—

(1) It is necessary to expose the grain-weevil *Sitophilus oryzae* to an atmosphere containing about 150 parts of HCN per 100,000 parts of air for about 20 hours in order to ensure killing it outright (pages 104, 106). Short exposures at high HCN-concentration are not so satisfactory as long exposures at lower HCN-concentrations (page 105).

(2) The Mexican boll-weevil is relatively more sensitive than the grain-weevil to exposures for a comparatively short time at high HCN-concentrations (page 108). It is inferred that an exposure of Mexican boll-weevils to an atmosphere containing at least 150 parts of HCN per 100,000 parts of air for 20 hours will be sufficient to kill them, especially if for some hours the HCN-concentration is considerably higher than 150 parts per 100,000 (page 109).

(3) The actual lethal HCN-concentration and period of exposure for both grain-weevils and boll-weevils depend upon the vitality of the weevils, and this is greatly affected by the temperature, and possibly by the humidity (pages 103—4, 106).

(4) Cotton, whether baled or in the loose state, rapidly absorbs up to about 0·02 of its own weight of HCN (page 135) in an atmosphere containing 150 parts HCN per 100,000 air.

(5) Cotton rapidly desorbs HCN (page 135).

(6) The absorptive power of cotton depends somewhat upon its moisture content: cotton which had been dried over fused calcium chloride had a lower absorptive power than air-dry cotton, while the latter was less absorptive than very damp cotton (pages 118, 122—28).
The results obtained with cotton dried over concentrated sulphuric acid were anomalous, presumably owing to the cotton taking up some of the acid from the vapour, the acid itself being a strong absorbent of HCN (pages 98—99, 122—23).

(7) The absorptive power of cotton remains practically unchanged throughout the range of temperature 86° F.—104° F. (pages 114, 121, 128).

(8) For the saturation of cotton with HCN in an atmosphere containing 150 parts HCN per 100,000 air by volume the amount of sodium cyanide required is about 0·05 per cent. of the weight of the cotton (page 135).

(9) Jute, as used for the gunny covering of cotton bales, has a much higher and more rapid absorptive power than cotton for HCN, absorbing

about 0·04 per cent. of its own weight of HCN in an atmosphere containing 150 parts HCN per 100,000 (page 141).

(10) The absorptive power of jute is not greatly affected by its moisture content, being slightly greater and more rapid for damp jute than for dry jute (page 139).

(11) The absorptive power of jute is practically independent of the temperature throughout the range 86°F.—104° F. (pages 139—40).

(12) For the saturation of jute with HCN in an atmosphere containing 150 parts HCN per 100,000, the amount of sodium cyanide required is about 0·10 per cent. of the weight of the jute (page 140).

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APPENDIX I.

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant.

Precis	Author	Original	Abstract
Experiments on destruction of larvæ in roots by gaseous hydrogen cyanide. Best results are obtained under vacuum conditions.	E. R. Sasscer . H. L. Sandford .	*J. Agric. Res.* 1918, *15*, 133.	*Physiol, Abstrs.* 1919, *4*, 109. *Chem. Abstrs.* 1919, *13*, 357.
Destruction of larvæ of black walnut worm on orchids by hydrogen cyanide.	E. R. Sasscer . H. F. Dietz .	*J. Agric. Res.* 1918, *15*, 263.	*Physiol, Abstrs.* 1919, *4*, 199.
Directions for preparation and use of gaseous hydrogen cyanide for destroying vermin in clothes, and eggs, larval, pupal and imago stages of insects.	W. G. Liston . S. N. Goré.	*Proc. Asiatic Soc. Bengal* 1919, *15*, 109.	*Chem. Abstrs.* 1920, *14*, 1404.
Study of effects of hydrogen cyanide on tomato plant tissues. Permanent injury results from a dose of 0·007 gm. potassium cyanide per cubic foot of air.	E. E. Clayton .	*Bot. Gaz.* 1919, *67*, 483	*Physiol, Abstrs.* 1919, *4*, 367.
Use of hydrogen cyanide as insecticide compared with other substances.	G. Bertrand . M. Rosenblatt.	*Compt. rend.* 1919, *168*, 911.	*Chem. Abstrs.* 1919, *13*, 1740.
Action of hydrogen cyanide on organisms of plants; spores of *B. subtilis* and *B. mesentericus vulgatus* are destroyed by 3·5 vols. of hydrogen cyanide in 100 vols. of air in 24 hours at 13°—14°C. *Mucor mucedi* and *M. stolonifer* are destroyed by 3·5 vols. Penicillium glaucum by 4 vols. *Tilletia tritici* by 2 vols. in 24 hours at 16°C. Seeds of *Triticum vulgare. Hordeum distichum* and *Beta vulgaris* exposed to .2 vols. and then ventilated for 3 days at 25°C are not injured. Gas is more effective at 16° than at 10°C.	J. Stoklasa . .	*Compt. rend.* 1920, *170*, 1404.	*Nature*, 1920, *105*, 539. *J. Chem. Soc.* 1920, *118*, i, 516. *Physiol. Abstrs.* 1921, *5*, 499. *Chem. Abstrs.* 1920, *14*, 2674.
Effect of hydrogen cyanide on plants. Green cress is killed in 10 days by 0·24 mg. of acid per litre of air. 71·3 mg. of acid per litre of air have same effect on seeds in water; 2·375 mg. impair their germination and development.	C. Wehmer . .	*Biochem. Zeitsch.* 1918, *92*, 364.	*J. Chem. Soc.* 1920, *118*, i, 273. *J. Soc. Chem. Ind.* 1920, *39*, 167A.
Results of comparative tests of efficacy of liquid and gaseous hydrogen cyanide in killing scale insects and ladybird beetles in citrus trees. Gas is more effective at top of tree.	H. J. Quayle .	*Calif. Agr. Expt. Sta. Bull.* 1919, *308*, 393.	*Chem. Abstrs.* 1920, *14*, 86.
Experiment to determine risk of poisoning during disinfection of rooms by hydrogen cyanide. 670 gm. of acid were liberated in room of 42·5 cu. m. All moths, flies, mice and ants were killed in 15 hours. Gas was removed by 10 hours ventilation, except in case of cushions.	H. Führer . .	*Pharm. Zentr. h.* 1919, *60*, 487.	*J. Soc. Chem. Ind.* 1920, *39*, 79A. *Chem. Abstrs.* 1920, *14*, 1003.

APPENDIX I—*contd.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—contd.

Precis	Author	Original	Abstract
Comparative tests of toxic action of various gases on insects, seeds and fungi. Hydrogen cyanide has less effect than chloropicrin and the same as cyanogen chloride in fumigating stored products.	I. E. Neifert . G. L. Garrison .	*U. S. Dept. Agr. Bull.* 1920, *893*, 1.	*Chem. Abstrs.* 1921, *15*, 140.
Comparative action of hydrogen cyanide, and various cyanogen derivatives (cyanogen chloride and bromide, methyl cyanoformate and "Cyclon" which consists of methyl and ethyl esters of cyanoformic acid and "Cl. ester") on cats, mice, insects such as bedbugs and cockroaches, green plants and wheat seeds.	F. Flury . . A. Hase.	*Munch. med. Woch.* 1920, *67*, 779.	*Chem. Abstrs.* 1921, *15*, 722.
Method of using apparatus for generating gaseous hydrogen cyanide for destroying insects and fungi on citrus trees.	....	*Scient. Amer.* 1922, *3*, No. 5.	
Investigation of most favourable conditions for use of gaseous hydrogen cyanide for destruction of bacteria. It is more effective with increase in temperature, low moisture content and in strong light. *Staphylococcus aureus and B. coli* on a dry substratum are killed in 24 hours by a concentration of 2·25—2·5 per cent. by vol. at 24—28°C, in an atmosphere of 15—20 per cent. saturation in diffused light.	E. Teichmann W. Nagel.	*Z. Hyg. Infektionskrankh.* 1920, *90*, 401.	*Chem. Abstrs.* 1921, *15*, 4017.
Experiments on control of San Jose scale. Hydrogen cyanide did not control the scale completely and all strengths injured plant.	K. C. Sullivan.	*Missouri Agr. Expt. Stat. Bull.* 1921, *117*, 1.	*Chem. Abstrs.* 1921, *15*, 3174.
Description of method for suppression of Red Scale and other "hard" scale insects in citrus trees by means of hydrogen cyanide.	C. P. Lounsbury .	*J. Dept. Agr. Union. S. Africa* 1921, *2*, 437.	*Chem. Abstrs.* 1921, *15*, 3174.
Summary of work on methods of using hydrogen cyanide for fumigating purposes.	G. Harker . .	*J. Soc. Chem. Ind.* 1921, *40*, 183T.	
Method of using gaseous hydrogen cyanide for destroying lice, grain and vegetable pests. 0·6 per cent. by volume is effective in ½ hour. Method of recovery of hydrogen cyanide from atmosphere.	Dout. Gold & Silber-Scheid. vorm. Roessler.	*G. P.* 347, 847-8. Jan. 25, 1922.	*Chem. Zentr.* 1922, *93*, II, 1215.
Details of fatality resulting from use of hydrogen cyanide for destroying moths.	H. Heller . .	*Zeitsch. angew. Chem.* 1920, *33*. Aufsatzteil 157.	*Chem. Abstrs.* 1921, *15*, 3719.
Danger resulting from use of hydrogen cyanide for disinfecting buildings. Cyklon is less objectionable in this respect.	Wolf . . .	*Pharm. Zeit.* 1922, *67* 316.	*Chem. Abstrs.* 1922, *16*, 2379.
Opposition to use of hydrogen cyanide or disinfecting buildings on account of fatalities.	E. Gilbricht . .	*Desinfektion* 1921, *6*, 353.	*Chem. Zentr.* 1922, *93*, II, 59.

APPENDIX I—*contd.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—contd.

Precis	Author	Original	Abstract
Advantages and disadvantages of use of compressed hydrogen cyanide for fumigating purposes.	E. V. Espenhahn	*Chem. & Met. Eng.* 1922, *26*, 939.	
Use of hydrogen cyanide in inhabited places.	Selter	*Deut. med. Wchschr.* 1919, *45*, 872.	
Technique of use of hydrogen cyanide	E. V. Skramlik	*Hyg. Rundschau.* 1919, *29*, 71.	
Survey of hydrogen cyanide as insecticide.	W. C. Liston S. N. Gore.	*Indian J. Med. Res.* 1919, *6*, 40.	
Use of hydrogen cyanide for destruction of rats.	C. L. Claremont	*J. Soc. Chem. Ind.* 1921, *40*, 327R.	*Chem. Abstrs.* 1922, *16*, 310.
Description of portable hydrogen cyanide generator and process for fumigating small compartments of ships.	C. M. Fauntleroy	*Public Health Repts.* 1921, *Reprint No. 673.*	*Chem. Abstrs.* 1922, *16*, 777.
Description of apparatus for destroying destructive bugs on trees by hydrogen cyanide.	....	*Scient. Amer.* 1921, No. 22.	
Advantages of heat over hydrogen cyanide as insecticide.	J. P. Calderwood	*Heating & Ventilating Mag.* 1922, *19*, 25.	*J. Ind. Hyg.* 1922, *4*, 48A.
Non-bactericidal action of hydrogen cyanide.	Deut. Ges. für Schädlingsbe kämpfung.	*Chem. Zeit.* 1922, *46*, 281.	*Chem. Zentr.* 1922, *93*, II, 989.
Probable replacement of hydrogen cyanide for fumigating ships by easily detected cyanogen chloride.	....	....	*Chem. & Met. Eng.* 1922, *27*, 39 : 529. *J. Soc. Chem. Ind.* 1922, *41*, 419R.
Inhibition of respiratory and fermentative activity of animal cells by mixtures of narcotics and hydrogen cyanide.	W. Lipschitz A. Gottschalk.	*Pflügers Arch.* 1921, *191*, 1 : 33.	*Chem. Abstrs.* 1922, *16*, 2525.
Influence of hydrogen cyanide on respiration and assimilation of living cells.	O. Warburg	*Zeitsch. Elektrochem.* 1922, *28*, 70.	*Chem. Zentr.* 1922, *93*, I, 1076. *J-Chem. Soc.* 1922, *122*, I, 787.
Action of hydrogen cyanide on various bacteria and yeast.	E. V. Skramlik	*Centr. Bakt. Par.* 1919, Abt. I. *Orig. 83*, 386.	*Chem. Abstrs.* 1922, *16*, 2707.
Bibliography of use of hydrogen cyanide as disinfectant.	Wolf	*"Off Gesundheitspflege"* 1922, *7*, 126.	*Chem. Zentr.* 1922, *93*, IV, 342. *Chem. Abstrs.* 1923, *17*, 788.
Use of hydrogen cyanide and mixtures containing hydrogen cyanide by French during war. French war production of Vincennite.	C. J. V. Nieuwenburg.	*Chem. Weekblad.* 1922, *19*, 326.	*Chem. Zentr.* 1922, *93*, IV, 984.
Experiments on use of mixtures of hydrogen cyanide and lachrymators or ship fumigation. Advantages of cyanogen chloride.	....	*Pub. Health Rpts.* 1922, *37*, 2744.	*Chem. Abstrs.* 1923, *17* 1522.

APPENDIX I—*contd.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—contd.

Precis	Author	Original	Abstract
Superheating and fumigation with carbon disulphide and hydrogen cyanide proved effective in killing larvæ present in wheat stored in elevators.	M. A. Hussain	*Rept. Operations Dept. Agr. Punjab* 1920-21, Part 2, 52.	*Chem. Abstrs.* 1923, *17*, 847.
Absorption of hydrogen cyanide by foodstuffs during fumigation of liner.	J. D. Jansen W. Schut. M. Wagnenaar.	*Chem. Weekblad.* 1922, *19*, 373.	*J. Soc. Chem. Ind.* 1922, *41*, 873A. *Chem. Zentr.* 1922, *93*, IV, 1019.
Description of process of fumigation of yacht with hydrogen cyanide.	....	*Engineering*, 1922, *114*, 399.	
Fumigation of green-houses with hydrogen cyanide.	E. R. Sasscer C. A. Wiegel	*J. Econ. Entomology*, 1922, *15*, 200.	*Chem. Abstrs.* 1922, *16*, 3726.
		J. Econ. Entomology, 1923, *16*, 84.	*Chem. Abstrs.* 1923, *17*, 1525.
Discussion of use of hydrogen cyanide as insecticide, parasiticide and vermicide.	E. Bonjean	*Rev. d'Hyg.* 1922, *44*, 776.	*Chem. Zentr.* 1922, 93 IV, 1100. *Chem. Abstrs.* 1923, *17*, 605.
Use of hydrogen cyanide for ant control on board ship.	W. T. Clark	*J. Econ. Entomol.* 1922, *15*, 329.	*Chem. Abstrs.* 1922, *16*, 4284.
Development of fumigating gas containing hydrogen cyanide and cyanogen chloride by C. W. S.	....	*Amer. Assoc. Advancement Sci.*	*J. Soc. Chem. Ind.* 1923, *42*, 98.
Bibliographies of use of hydrogen cyanide as insecticide.	....	....	*J. Ind. Eng. Chem.* 1922, *14*, 1148.
Resistance of scale insects in some localities to hydrogen cyanide.	H. J. Quayle	*J. Econ. Entomol.* 1922, *15*, 400.	*Chem. Abstrs.* 1923, *17*, 446.
Toxicity of hydrogen cyanide for Phlebotomes.	E. Pringeault	*Compt. rend. Soc. biol.* 1922, *87*, 846.	*Chem. Zentr.* 1923, *94*, 1, 802. *Chem. Abstrs.* 1923, *17*, 1080.
Absorption of hydrogen cyanide by food-stuffs during fumigation.	....	*U. S. Bur. Chem.*	*Chem. & Met. Eng.* 1923, *28*, 829.
Dangers of disinfection by hydrogen cyanide.	C. Marini	*L'Igiene Moderna.* 1921, *14*, 294.	
Experiments on disinfection and destruction of rats by hydrogen cyanide.	L. Piras	*L'Igiene Moderna.* 1921, *15*, 101; 129.	*Chem. Abstrs.* 1923, *17*, 1682.
Apparatus for fumigation by hydrogen cyanide.	....	*Lancet*, 1923, *5207*, 1223.	
Use of hydrogen cyanide by public services for disinfection.	P. Almasio	*Riv. ing. sanit. edilizia moderna*, 1921, *17*, 97; [illegible]	*Chem. Abstrs.* 1923, *17*, 1682.
Use of hydrogen cyanide for disinfection.	A. Filippini	*Ann. d'ig* 1921 *31*, 419.	
Absorption and retention of hydrogen cyanide by fumigated food products.	E. L. Griffin I. E. Neifert. N. Perrine. A. B. Duckett.	*U. S. Dept. Agric. Bull.* 1923, *1142*, 1.	*Chem. Abstrs.* 1923, *17*, 2820.

APPENDIX I—*contd.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—contd.

Precis	Author	Original	Abstract
Inefficiency of hydrogen cyanide against plague bacilli.	N. Bruni . .	*L'Igiene Moderna* 1922, *15*, 353.	*Chem. Abstrs.* 1923, *17*, 2761.
Description of machine for fumigation of ships with hydrogen cyanide.	W. G. Liston . S. N. Gore.	*J. Hyg.* 1923, *21*, 199 .	*Chem. Abstrs.* 1923, *17*, 2929.
Account of development of fumigation of ships by hydrogen cyanide and methods employed.	G. W. Monier-Williams. P. G. Stock . .	*J. Soc. Chem. Ind.* 1923, *42*, 1103. *Public Health Rep.* 1923, *19*.	*Journ. R. A. M. C.* 1924, *42*, 147.
Use of hydrogen cyanide for protection against clothes moths.	E. A. Back . .	*U. S. Dept. Agric. Farmers, Bull.* 1923, *1353*.	*Nature*, 1923, *112*, 881.
Use of hydrogen cyanide against vermin	Edit. Rep. . .	*Chem. & Met.* 1923, *29*, 1095.	
Description of buildings for umigation of railway cars.	....	*Chem. & Met.* 1923, *29*, 1160.	
Use of hydrogen cyanide as bactericide	W. C. Reynolds .	*Lancet.* 1922, ii, 834.	
Sanitary applications of hydrogen cyanide.	J. S. Beavis . .	*Bull. Office Intern. d'hyg. pub. Par.* 1922, *14*, 248.	
Use of hydrogen cyanide with cyanogen chloride as lachrymatory warning.	....	*U. S. Quarantine Reg. Amend. No. 6.*	*Ind. Eng. Chem.* 1924, *16*, 267.
Advantages of hydrogen cyanide as insecticide.	Lp. de Costobadie .	*Nature*, 1923, *112*, 791 .	
Death penalty carried out by hydrogen cyanide.	....	*Scient. Amer.* 1924, *130*, 231.	
History of use of hydrogen cyanide as insecticide.	R. S. Woglum	*J. Econ. Entomol.* 1923, *16*, 518.	*Chem. Abstrs.* 1924, *18*, 1028.
Use of hydrogen cyanide to clear out bed-bugs.	J. H. Collins	*Scient. Amer.* 1924, *130*, 392.	
Use of hydrogen cyanide for rat destruction in ships.	....	*Arch. de med. et pharm. nav.* 1922, *120*, 491.	
Fatalities from hydrogen cyanide in fumigation.	....	*Weekly Bull. U. S. Dept. Health* 1923, *12*, 265.	
Recent developments in use of hydrogen cyanide for greenhouse fumigation.	E. R. Sasscer . C. A. Weigel.	*J. Econ. Entomol.* 1924, *17*, 214.	*Chem. Abstrs.* 1924, *18*, 2404.
Survey of recent progress in use of hydrogen cyanide as fumigant.	C. C. McDonnell .	*Ind. Eng. Chem.* 1924, *16*, 1010.	
Effect of hydrogen cyanide for ship fumigation on food materials. Benzidine copper acetate test for hydrogen cyanide.	P. Buttenberg . H. Weiss.	*Z. unters. nahr. Genussm.* 1924, *48*, 104.	*Analyst*, 1924, *49*, 533. *J. Soc. Chem. Ind.* 1924, *43*, 994B. *Chem. Abstrs.* 1924, *18*, 3657.
Lecture on fumigation by hydrogen cyanide.	W. Glen-Liston .	*J. Soc. Chem. Ind.* 1925, *44*, 367.	*J. Soc. Chem. Ind.* 1924, *43*, 1296.
Absorption and retention of hydrogen cyanide during fumigation of food products.	E. L. Griffin . . E A Back.	*U. S. Dept. Agric. Bull.* 1307 (1924).	*Chem. Abstrs.* 1925, 682. *Ind. Eng. Chem.* (News) 1925, *3*, (1) 5.

APPENDIX I—*contd.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—contd.

Precis	Author	Original	Abstract
Precautions against absorption of hydrogen cyanide in disinfection uses.	A. Cavidalli	*Arch. ital. de biol.* 1924, *73*, 61. *Ber. ges. physiol.* 1924, *27*, 468.	*Chem. Zentr.* 1925, *96*, I, 409.
Efficiency of hydrogen cyanide in fumigation of warehouses filled with sacks. Effect on various plant pests.	E. A. Back R. T. Cotton.	*J. Agric. Res.* 1924, *28*, 649.	*Chem. Zentr.* 1925, *96*, I, 566.
Lethal concentrations of hydrogen cyanide for various insects infesting railway coaches.	L. Kulikow	*Trans. Inst. Pure Chem. Reagents* 1924, (3) 19, (Russ.).	*Chem. Zentr.* 1925, *96*, I, 721.
Successful use of hydrogen cyanide in fumigation against hide beetles.	....	*Chem. & Met. Eng.* 1925, *32*, 259.	
Historical review of the use of hydrogen cyanide as a fumigating agent.	W. G. Liston	*J. Soc. Chem. Ind.* 1925, *44*, 367.	*Chem. Abstrs.* 1925, *19*, 1921. *J. Soc. Chem. Ind.* 1925, *44*, 523B. *Chem. Zentr.* 1925, *96*, II, 230.
Consumption of materials and output of gas by various types of hydrogen cyanide fumigators.	G. Harker	*J. Soc. Chem. Ind.* 1925, *44*, 847.	*Chem. Zentr.* 1926, *97*, I.
Criticism of above article	W. G. Liston	*J. Soc. Chem. Ind.* 1925, *44*, 891.	
Exposure to low concentrations of hydrogen cyanide stimulates plant growth.	G. Gassner	*Ber. deut. bot. Ges.* 1925, *43*, 132.	*J. Soc. Chem. Ind.* 1925, *44*, 644B.
Use of hydrogen cyanide for the destruction of the white fly in tomato-houses.	E. R. Speyer O. Owen.	*Nature* 1925, *116*, 644	*Chem. Zentr.* 1926, *97*, I, 1021.
Four fatalities at Tricste during fumigation of a ship with hydrogen cyanide (despite gas masks).	....	*Chem. Age.* 1925, *13*, 474.	
Increasing use of hydrogen cyanide as a fumigant for ships.	....	*Ind. Eng. Chem.* (News) 1925, *3*, (19) 7.	
Suggested addition of lachrymator to hydrogen cyanide to safeguard fumigation workers.	....	*Ind. Eng. Chem.* 1925, *17*, 1,000.	
Utilisation of hydrogen cyanide for the destruction of pear tree pests.	R. L. Webster	*New York Agric. Exptl. Station Bull. 523*, 1924.	*Chem. Zentr.* 1926, *96*, II, 979.
Comparison of hydrogen cyanide with other agents for disinfection of living spaces. (Costs, etc.).	....	*Lancet.* 1925, *5324*, 580.	
Analytical data on hydrogen cyanide content of foods after fumigation.	P. Buttenberg W. Deckert. G. Gartz.	*Z. Nahr. Genussm.* 1925, *50*, 92.	*Chem. Abstrs.* 1926, *20*, 244. *Chem. Zentr.* 1926, *97*, I, 523.
Practical observations on disinfection by hydrogen cyanide.	S. Paoli	*Annali d'Igiene* 1925, *35*, 872.	*Chem. Zentr.* 1926, *97*, I, 1598.
Destruction of cockroaches and their eggs by hydrogen cyanide.	C. E. Rice	*U. S. Pub. Hlth. Repts.* 1925, *40*, 1808.	*Chem. Abstrs.* 1925, *19*, 3336. *Brit. Chem. Abstrs.* 1925, *B*, 30.

APPENDIX I—*concld.*

Recent References in the Scientific Literature to the use of Hydrogen Cyanide as a Fumigant—concld.

Precis	Author	Original	Abstract
Destruction of vermin by hydrogen cyanide maximum effective concentration.	R. Newstead A. E. Evans. W. H. Potts.	*Ann. Trop. Med. & Parasitol.* 1925, *19*, 91.	*Chem. Abstrs.* 1925, *19*, 3336.
Concentrations of hydrogen cyanide dangerous to man met with in fumigation 1/5000.	W. G. Liston	*J. Soc. Chem. Ind.* 1925, *44*, 367.	*J. Ind. Hyg.* 1925, *7*, 197A.
Effect of fumigating cold storage with hydrogen cyanide.	P. Buttenberg W. Deckert. Gahratz.	*Z. Untes. Nahr. Genussm.* 1925, *50*, 92-103.	*J. Soc. Chem. Ind.* 1925, *44*, B, 969.
Use of hydrogen cyanide for fumigation purposes in conjunction with a lachrymator, so as to give warning of the presence of HCN.	....	*Chem. and Met. Eng.* 1921, *25*, 1155.	
Preparation for destroying insects on trees by mixing gaseous hydrogen cyanide with an irritant such as mustard gas.	J. D. Neuls	*U. S. P.* 1381, 586, June 14, 1921.	*J. Soc. Chem. Ind.* 1921, *40*, 600A. *Chem. Abstrs.* 1921, *15*, 3537.
Hydrogen cyanide is more effective for extermination of insects in buildings if oxygen content of air is diminished by burning charcoal.	C. Schierholz	*Oesterr-Chem-Zeit* 1921, *24*, 166.	*Chem. Abstrs.* 1922, *16*, 1115.
Bactericidal action of mixtures of hydrogen cyanide with hydrogen sulphide, chloroform, sulphur dioxide, Cyklon and formaldehyde. Latter mixture was only one which was more effective than hydrogen cyanide alone.	W. Nagel	*Desinfektion* 1921, *6*, 349.	*Chem. Zentr.* 1922, *93*, II, 171.
Probable replacement of gaseous hydrogen cyanide by the easily detected cyanogen chloride for fumigation of ships.	....	....	*Chem. and Met. Eng.* 1922, *27*, 39.

APPENDIX II.

A. Results of Analyses of Cyanides.

Sample	Substances present	Percentage Composition					
		Volumetric determination. (Liebig's method) *	Gravimetric determination (Murry's method) †			Volumetric determination (Treadwell and Hall's method) ‡	
			1	2	3	1	2
Sodium cyanide A	Sodium cyanide	91·1	92·3	89·8	89·6	91·2	91·2
	Sodium chloride	..	4·1	3·5	3·5	4·8	2·9
Sodium cyanide B	Sodium cyanide	88·6	90·2	..	87·9	86·5	87·7
	Sodium chloride	..	4·4	..	3·7	4·9	4·9
Potassium cyanide A	Potassium cyanide	96·5	96·9	95·8	95·0	95·1	95·1
	Potassium chloride	..	2·1	3·5	4·6	6·3	3·8
Potassium cyanide B	Potassium cyanide	93·5	95·1	..	83·0	95·1	95·1
	Potassium chloride	..	3·5	..	2·8	1·6	3·8

* Ann. Chem. Pharm. (77) 102 ; or Treadwell and Hall, " Quantitative Analysis ", 1924, 606.
† Murry, " Standards and Tests for Reagent Chemicals," 1920, 319.
‡ Treadwell and Hall, " Quantitative Analysis ", 1924, 607.

APPENDIX II—*contd.*

B. Results of Analyses of Synthetic Mixtures of Cyanides and Chlorides.

	Synthetic mixture	Percentage Composition				
		Actual	Volumetric estimation (Treadwell and Hall's* method)		Gravimetric estimation (Murry's method)†	
			(1)	(2)	(1)	(2)
1.	Sodium cyanide A	60	54·7	54·7	53·8	53·8
	Sodium chloride	40	41·7	42·9	42·1	42·1
2.	Sodium cyanide B	60	53·1	52·6	..	52·7
	Sodium chloride	40	42·9	42·9	..	42·2
3.	Potassium cyanide A	60	57·0	57·0	57·4	57·0
	Potassium chloride	40	43·8	42·3	42·1	42·7
4.	Potassium cyanide B	60	57·0	57·0	..	57·4
	Potassium chloride	40	40·8	42·3	..	41·7

* Treadwell and Hall, "Quantitative Analysis", 1924, 607.
† Murry, "Standards and Tests for Reagent Chemicals", 1920, 319.

APPENDIX II—*contd.*

C. Results of Estimations of HCN generated from various Cyanides and Mixtures in the Small-Scale Fumigation Apparatus.

Date	Sample	Charge	Volume displaced c.c.	Standard silver nitrate solution required c.c.	HCN-Concentration	
					Parts per 100,000	Percentage of theoretical value
22nd August 1925	Sodium cyanide A	Sodium cyanide . 0·10 gram	1,250	25·5	306	71
20th October 1925	Ditto	Sodium cyanide . 0·06 „ Sodium chloride . 0·04 „	500	6·0	180	70
20th October 1925	Ditto	Sodium cyanide . 0·06 „ Sodium chloride . 0·04 „	500	6·0	180	70
12th October 1925	Sodium cyanide B	Sodium cyanide . 0·10 „	1,000	19·0	285	67
19th October 1925	Ditto	Sodium cyanide . 0·06 „ Sodium chloride . 0·04 „	500	6·0	180	70
19th October 1925	Ditto	Sodium cyanide . 0·06 „ Sodium chloride . 0·04 „	500	5·8	175	68

APPENDIX II—*contd.*

C. Results of Estimations of HCN generated from various Cyanides and Mixtures in the Small-Scale Fumigation Apparatus—contd.

Date	Sample	Charge	Volume displaced c.c.	Standard silver nitrate solution required c.c.	HCN-Concentration	
					Parts per 100,000	Percentage of theoretical value
21st August 1925 .	Potassium cyanide A	Potassium cyanide . 0·20 gram	1,250	41·3	496	77
19th October 1925 .	Ditto	Potassium cyanide . 0·06 ,, Potassium chloride . 0·04 ,,	500	4·9	148	75
19th October 1925 .	Ditto	Potassium cyanide . 0·06 ,, Potassium chloride . 0·04 ,,	500	5·0	150	77
13th October 1925	Potassium cyanide B	Potassium cyanide . 0·10 ,,	500	8·6	258	79
19th October 1925	Ditto	Potassium cyanide . 0·06 ,, Potassium chloride . 0·04 ,,	500	5·1	153	79
19th October 1925 .	Ditto	Potassium cyanide . 0·06 ,, Potassium chloride . 0·04 ,,	500	5·1	153	79

APPENDIX III.

TABLE I.

Results of Tests to determine the Effects of Hydrocyanic Acid Gas on the Boll Weevil. Tallulah, La., October-November 1924, by G. L. Smith.

Date	Test Number	Time			Concentration of HCN Gas	Temperature °F.		Number of Weevils			Per cent. Weevils		Condition Temperature at starting
		Started	Opened	Hours Exposure		Max.	Min.	Used	Dead	Alive	Dead	Alive	
Oct. 15	1	11-54 a.m.	1-54 p.m.	2	1,500 to 100,000	..	..	26	26	0	100	..	Rising.
,, 15	2	2-45 p.m.	4-45 p.m.	2	1,500 ,, 100,000	88	78	22	22	0	100	..	Lowering.
,, 16	3	9-15 a.m.	11-15 a.m.	2	1,500 ,, 100,000	86	56	25	25	0	100	..	Rising.
,, 16	4	11-30 a.m.	1-30 p.m.	2	1,500 ,, 100,000	90	71	25	25	0	100	..	,,
,, 16	5	1-45 a.m.	3-45 p.m.	2	1,500 ,, 100,000	99	73	25	25	0	100	..	Lowering.
,, 16	6	3-55 p.m.	5-55 p.m.	2	1,500 ,, 100,000	99	73	25	25	0	100	..	,,
,, 17	7	10-15 a.m.	12-15 p.m.	2	1,500 ,, 100,000	86	72	25	25	0	100	..	Rising.
,, 17	8	1-35 p.m.	3-35 p.m.	2	1,500 ,, 100,000	97	84	25	25	0	100	..	Lowering.
,, 17	9	3-55 p.m.	5-55 p.m.	2	750 ,, 100,000	92	73	25	25	0	100	..	,,
,, 18	10	8-05 a.m.	10-05 a.m.	2	750 ,, 100,000	75	55	25	25	0	100	..	Rising.
,, 18	11	10-15 a.m.	12-15 a.m.	2	750 ,, 100,000	89	72	25	25	0	100	..	,,
,, 18	12	1-30 p.m.	3-30 p.m.	2	750 ,, 100,000	..	..	25	25	0	100	..	,,
,, 29	26	8-15 a.m.	10-15 a.m.	2	750 ,, 100,000	78	50	25	25	0	100	..	,,
,, 20	13	11-00 a.m.	1-00 p.m.	2	375 ,, 100,000	95	80	25	25	0	100	..	,,
,, 20	14	1-10 p.m.	3-10 p.m.	2	375 ,, 100,000	97	90	25	25	0	100	..	Lowering.
,, 20	15	3-15 p.m.	5-15 p.m.	2	375 ,, 100,000	85	80	25	25	0	100	..	,,
,, 24	21	3-15 p.m.	5-15 p.m.	2	375 ,, 100,000	85	65	25	18	7	72	28	,,
,, 27	22	4-00 p.m.	6-00 p.m.	2	375 ,, 100,000	73	60	25	17	8	68	32	,,
,, 28	23	8-45 a.m.	10-45 a.m.	2	375 ,, 100,000	63	40	25	0	25	..	100	Rising.

APPENDIX III—*contd.*

TABLE I—*contd.*

Results of Tests to determine the Effects of Hydrocyanic Acid Gas on the Boll Weevil. Tallulah, La., October-November 1924, by G. L. Smith—contd.

Date	Test Number	Time			Concentration of HCN Gas	Temperature °F.		Number of Weevils			Per cent. Weevils		Condition Temperature at starting
		Started	Opened	Hours Exposure		Max.	Min.	Used	Dead	Alive	Dead	Alive	
Oct. 28 .	24	1-20 p.m.	3-20 p.m.	2	375 to 100,000	84	76	25	23	2	92	8	Lowering.
„ 29 .	27	1-30 p.m.	3-30 p.m.	2	375 „ 100,000	97	70	25	25	0	100	..	„
„ 31 .	29	11-00 a.m.	1-00 p.m.	2	300 „ 100,000	70—72	60—63	25	25	0	100	..	Rising.
„ 31 .	30	1-15 p.m.	3-15 p.m.	2	300 „ 100,000	72—74	63	25	22	3	88	12	
Nov. 1 .	31	4-15 p.m.	4-15 p.m.	24	300 „ 100,000	71—88	..	25	25	0	100	0	Lowering.
„ 21 .	16	1-40 p.m.	3-40 p.m.	2	150 „ 100,000	90	80	25	21	4	84	16	„
„ 21 .	17	3-40 p.m.	9-40 p.m.	6	150 „ 100,000	85	55	25	22	3	88	12	„
„ 22 .	18	9-00 a.m.	3-00 p.m.	6	150 „ 100,000	82	50	25	10	15	40	60	Rising.
„ 22 .	19	3-00 p.m.	3-00 p.m.	24	150 „ 100,000	83	36	25	8	17	32	68	Lowering.
„ 23 .	20	3-10 p.m.	3-10 p.m.	24	150 „ 100,000	85	29	25	10	15	40	60	„
„ 30 .	28	10-00 a.m.	10-00 a.m.	24	150 „ 100,000	95	45	25	16	9	64	36	Rising.
„ 4 .	32	9-00 a.m.	9-00 a.m.	24	300 „ 100,000	88	48	25	25	0	100	..	
„ 5 .	33	9-00 a.m.	11-00 a.m.	2	450 „ 100,000	85	..	25	19	6	76	24	
„ 5 .	34	11-10 a.m.	1-10 p.m.	2	450 „ 100,000	90	..	25	25	0	100	..	
„ 5 .	35	1-15 p.m.	3-15 p.m.	2	450 „ 100,000	91	..	25	24	1	96	4	
„ 8 .	38	1-30 p.m.	7-30 p.m.	6	450 „ 100,000	80	..	25	25	0	100	..	
„ 10 .	39	10-00 a.m.	4-00 p.m.	6	450 „ 100,000	84	..	25	25	0	100	..	
„ 5 .	36	3-20 p.m.	3-20 p.m.	24	450 „ 100,000	91	56	25	25	0	100	..	
„ 6 .	37	3-30 p.m.	3-30 p.m.	24	450 „ 100,000	93	54	25	25	0	100	..	

APPENDIX III—*contd.*

TABLE II.

Results of Tests to determine the effects of Hydrocyanic Acid Gas on the Boll Weevil, by F. H. Tucker and V. V. Williams.

Date (1925).	Test Number	TIME			Concentration HCN gas by volumes	TEMPERATURE °F.		NUMBER OF WEEVILS			PER CENT. WEEVILS		TYPE OF WEEVILS		Type of Treatment
		Started	Opened	Exposure Hours		Max.	Min.	Used	Dead	Alive	Dead	Alive	Hibernated in Spanish Moss	Field Collected	
Nov. 12 .	1	1-40 p.m.	5-40 p.m.	4	374 to 100,000	71	71	30	30	..	100	..	..	30	Desiccator.
„ 12 .	2	8-30 p.m.	8-30 a.m.	12	450 „ 100,000	68	..	30	30	..	100	..	..	30	Box.
„ 13 .	3	9-25 p.m.	11-25 a.m.	2	450 „ 100,000	69	..	30	30	..	100	..	..	30	„
„ 13 .	4	10-27 a.m.	2-27 p.m.	4	230 „ 100,000	73	70	30	12	18	40	60	..	30	Desiccator.
„ 13 .	5	11-53 a.m.	1-53 p.m.	2	450 „ 100,000	86	..	30	30	..	100	..	..	30	Box.
„ 13 .	6	2-15 p.m.	4-15 p.m.	2	450 „ 100,000	85	..	30	30	..	100	..	..	30	„
„ 13 .	7	3-51 p.m.	6-51 p.m.	3	173 „ 100,000	70	68	30	14	16	47	53	..	30	Desiccator.
„ 13 .	8	4-32 p.m.	6-32 p.m.	2	300 „ 100,000	75	..	30	2	..	100	..	..	30	Box.
„ 14 .	9	8-52 a.m.	10-52 a.m.	2	300 „ 100,000	72	..	30	29	1	97	3	..	30	„
„ 14 .	10	10-32 a.m.	1-32 p.m.	3	403 „ 100,000	75	73	30	20	0	67	33	..	30	Desiccator.
„ 14 .	11	11-19 a.m.	1-19 p.m.	2	300 „ 100,000	82	..	30	30	..	100	..	..	30	Box.
„ 14 .	12	1-39 p.m.	2-39 p.m.	1	300 „ 100,000	81	..	30	30	..	100	..	..	30	„
„ 14 .	13	3-02 p.m.	4-02 p.m.	1	300 „ 100,000	85	..	30	30	..	100	..	..	30	„
„ 14 .	14	4-26 p.m.	5-26 p.m.	1	300 „ 100,000	77	..	30	29	1	97	3	..	30	„
„ 16 .	15	9 50 a.m.	12-50 p.m.	3	240 „ 100,000	72	68	30	8	22	27	73	..	30	Desiccator.
„ 16 .	16	10-21 a.m.	11-21 a.m.	1	375 „ 100,000	78	..	30	8	22	27	73	..	30	Box.
„ 16 .	17	11-40 a.m.	12-40 p.m.	1	375 „ 100,000	70	..	30	25	5	83	17	..	30	„
„ 16 .	18	1-55 p.m.	3-55 p.m.	2	375 „ 100,000	70	..	30	29	1	97	3	..	30	„
„ 16 .	19	2-05 p.m.	5-05 p.m.	3	288 „ 100,000	70	69	30	26	4	87	13	..	30	Desiccator.

APPENDIX III—*contd.*

TABLE II—*contd.*

Results of Tests to determine the effects of Hydrocyanic Acid Gas on the Boll Weevil by F. H. Tucker and V. V. Williams—contd.

Date (1925).	Test Number	Time			Concentration HCN gas by volumes	Temperature °F.		Number of Weevils			Per cent. Weevils		Type of Weevils		Type of Treatment
		Started	Opened	Exposure Hours		Max.	Min.	Used	Dead	Alive	Dead	Alive	Hibernated in Spanish Moss	Field Collected	
Nov. 16 .	20	4-14 p.m.	6-14 p.m.	2	375 to 100,000	70	..	30	30	..	100	..	..	30	Box.
,, 17 .	21	10-11 a.m.	2-11 p.m.	4	192 ,, 100,000	68	61	30	27	3	90	10	..	30	Desiccator.
,, 18 .	22	1-02 p.m.	5-02 p.m.	4	230 ,, 100,000	68	66	30	30	..	100	..	..	30	"
,, 19 .	23	10-47 a.m.	2-47 p.m.	4	211 ,, 100,000	66	65	30	29	1	97	3	..	30	,,
,, 20 .	24	11-30 a.m.	4-30 p.m.	5	269 ,, 100,000	72	66	30	23	7	77	23	..	30	,,
,, 21 .	25	10-55 a.m.	3-55 p.m.	5	211 ,, 100,000	70	66	30	23	7	77	23	..	30	,,
,, 23 .	26	2-30 p.m.	7-30 p.m.	5	230 ,, 100,000	63	61	30	18	12	60	40	..	30	,,
,, 24 .	27	10-43 a.m.	3-43 p.m.	5	192 ,, 100,000	72	69	30	30	..	100	..	30	..	,,
,, 25 .	28	9-45 a.m.	3-45 p.m.	6	192 ,, 100,000	73	63	30	30	..	100	..	30	..	,,
,, 28 .	30	11-50 a.m.	4-50 p.m.	5	192 ,, 100,000	66	62	30	30	..	100	..	30	..	"
,, 30 .	31	9-43 a.m.	1-43 p.m.	4	259 ,, 100,000	72	60	30	30	..	100	..	30	..	,,
,, 30 .	32	2-28 p.m.	7-28 p.m.	5	269 ,, 100,000	72	70	30	30	..	100	..	30	..	,,
Dec. 1 .	33	9-29 a.m.	1-41 p.m.	4·2	297 ,, 100,000	70	58	30	30	..	100	..	30	..	,,
,, 2 .	34	9-40 a.m.	1-40 p.m.	4	280 ,, 100,000	72	68	30	30	..	100	..	30	..	,,
,, 3 .	35	9-32 a.m.	1-44 p.m.	4·2	430 ,, 100,000	77	72	30	30	..	100	..	30	..	,,
,, 4 .	36	8-52 a.m.	12-52 p.m.	4	279 ,, 100,000	70	68	30	30	..	100	..	30	..	,,
,, 4 .	37	1-40 p.m.	5-40 p.m.	4	279 ,, 100,000	71	65	30	30	..	100	..	30	..	,,
,, 5 .	38	9-10 a.m.	1-10 p.m.	4	298 ,, 100,000	69	63	30	30	..	100	..	30	..	,,

APPENDIX III—*concld.*

TABLE III.

Desiccator Tests to determine the effect of Hydrocyanic Acid Gas on Field Collected Boll Weevil.

Date 1926	Test Number	Time		Hours Exposure	Concentration HCN gas volume in 100,000 volumes	Temperature °F.		Number of Weevils			Per cent. Weevils		Remarks
		Release	Remove			Max.	Min.	Used	Dead	Alive	Dead	Alive	
Sept. 8	1	11-30 a.m.	4-30 p.m.	5	259	90	86	30	30	..	100	..	Temperature increased.
„ 9	2	9-30 a.m.	11-30 p.m.	5	326	87	82	30	30	..	100	..	
„ 9	3	2-15 p.m.	7-15 p.m.	5	336	90	86	30	30	..	100	..	
„ 9	4	8-15 p.m.	18-15 a.m.	12	317	90	77	30	30	..	100	..	Temperature decreased.
„ 10	5	9-30 a.m.	1-30 a.m.	4	307	81	77	30	30	..	100	..	Temperature increased.
„ 10	6	2-45 p.m.	5-45 p.m.	3	355	86	84	30	30	..	100	..	
„ 15	7	11-00 a.m.	2-00 p.m.	3	375	88	86	30	30	..	100	..	
„ 15	8	3-30 p.m.	5-30 p.m.	2	326	90	90	30	30	..	100	..	Temperature constant.
„ 16	9	10-00 a.m.	11-00 p.m.	3	Check	88	82	30	..	30	..	100	Temperature increased.
„ 17	10	1-30 p.m.	4-30 p.m.	3	Check	90	88	30	..	30	..	100	
„ 22	11	9-30 a.m.	11-30 p.m.	2	336	81	79	30	30	..	100	..	
„ 22	12	2-00 p.m.	3-00 p.m.	1	297	74	74	30	30	..	100	..	Temperature constant.
„ 22	13	3-45 p.m.	4-45 p.m.	1	191	86	86	30	24	6	80	20	
„ 23	14	9-30 a.m.	10-30 a.m.	1	326	86	84	30	30	..	100	..	Temperature increased.
„ 28	15	9-15 a.m.	10-30 a.m.	1¼	315	79	75	30	30	..	100	..	

APPENDIX IV.

Large-Scale Results of Fumigation with Hydrocyanic Acid Gas.

Table I.—*Typical Monsoon Results.*

Barge No.	Date	No. of bales	Charges of cyanide lb.	Total weight of cyanide lb.	No. of bales per lb. of cyanide	Maximum concentration during day (Parts per 100,000)	Minimum concentration during day (Parts per 100,000)	Overnight concentration (Parts per 100,000)	Concentration on the following day (Parts per 100,000)
23	19th Aug. 1926	368	20, 20, 20, 10	70	5·2	660	285	490	55
13	Ditto	273	20, 20	40	6·8	775	450	680	60
30	Ditto	244	60	60	4·1	1,250	920	920	75
8	20th Aug. 1926	286	20, 20, 20	60	4·7	650	300	575	55
24	Ditto	372	20, 20, 20	60	6·2	670	330	560	90
31	21st Aug. 1926	254	20, 20, 20	60	4·2	840	350	660	25
28	Ditto	223	20, 20	40	5·6	690	285	305	75
22	Ditto	359	20, 20, 30	70	5·1	935	245	845	45
13	22nd Aug. 1926	281	20, 20, 10	50	5·6	1,250	310	485	75
30	Ditto	256	20, 20, 20	60	4·3	1,225	325	524	25
23	Ditto	378	20, 20, 30	70	5·4	1,070	240	495	45
8	24th Aug. 1926	263	20, 20, 20, 10	70	3·8	945	225	655	115
24	Ditto	322	40, 20, 10	70	4·6	450	170	315	30
13	26th Aug. 1926	165	20, 20, 10	50	3·3	915	310	690	207
8	1st Sept. 1926	233	20, 20, 10	50	4·7	650	370	375	60
13	Ditto	214	50	50	4·3	1,030	Started late	940	160
24	2nd Sept. 1926	280	30, 30	60	4·7	645	455	430	85
30	Ditto	192	60	60	3·2	835	Started late	905	60
8	5th Sept. 1926	235	20, 20, 10	50	4·7	925	245	420	80
28	Ditto	157	20, 20	40	3·9	840	255	760	55
13	Ditto	267	20, 20, 10	50	5·3	845	340	590	70
31	6th Sept. 1926	252	60	60	4·2	690	Started late	765	85
30	7th Sept. 1926	211	20, 20, 10	50	4·2	950	255	601	75
22	Ditto	380	30, 30, 10	70	5·4	910	580	624	100
20	Ditto	333	60	60	5·5	1,153	Started late	1,021	96
8	8th Sept. 1926	243	20, 20, 10	50	4·9	836	415	585	124
13	Ditto	76	20, 10	30	2·5	973	283	579	100
13	17th Sept. 1926	216	20, 20, 10	50	4·3	743	249	375	90
8	18th Sept. 1926	184	20, 20	40	4·6	977	295	546	30

APPENDIX IV—*contd.*

LARGE-SCALE RESULTS OF FUMIGATION WITH HYDROCYANIC ACID GAS—*contd.*

TABLE II.—*Typical Post-Monsoon Results.*

Barge No.	Date	No. of bales	Charges of cyanide lb.	Total of cyanide lb.	No. of bales per lb. of cyanide	Maximum concentration during day (Parts per 100,000)	Minimum concentration during day (Parts per 100,000)	Overnight concentration (Parts per 100,000)	Concentration on the following morning (Parts per 100,000)
24	5th Nov. 1926	403	30, 20, 10	60	6·7	785	315	625	105
22	Ditto	413	30, 30	60	6·8	965	240	825	95
8	8th Nov. 1926	235	20, 10, 10	40	5·9	625	250	413	150
22	9th Nov. 1926	330	30, 20, 10	60	5·5	1,232	250	875	80
8	10th Nov. 1926	183	20, 10	30	6·1	970	320	420	115
13	Ditto	221	20, 10	30	7·4	965	395	500	90
28	Ditto	206	20, 20, 10	50	4·1	710	315	630	110
30	Ditto	250	20, 10, 10	40	6·2	605	215	500	50
24	11th Nov. 1926	297	20, 20, 10	50	5·9	760	345	620	90
31	Ditto	196	20, 10, 10	40	4·9	815	345	715	10
22	12th Nov. 1926	283	20, 10, 16	46	6·1	870	270	505	75
23	Ditto	311	30, 20	50	6·2	1,325	270	500	60
8	Ditto	206	20, 20	40	5·1	935	315	520	80
13	13th Nov. 1926	224	20, 20	40	5·6	990	216	725	85
13	19th Nov. 1926	237	20, 20	40	5·9	878	318	612	95
22	Ditto	337	30, 20, 10	60	5·6	910	315	680	73
8	21st Nov. 1926	194	20, 10, 10	40	4·8	642	215	504	60
30	23rd Nov. 1926	217	20, 10, 10	40	5·4	900	263	563	18
23	24th Nov. 1926	395	30, 20, 10	60	6·6	1,450	305	500	160
24	Ditto	390	30, 10, 10	50	7·8	650	320	510	80
13	25th Nov. 1926	82	10, 5, 5	20	4·1	710	265	505	75
23	28th Nov. 1926	403	30, 20, 10	60	6·7	725	240	620	50
8	29th Nov. 1926	214	40	40	5·3	1,505	..	1,215	225
30	30th Nov. 1926	214	20, 20, 10	50	4·3	1,250	165	1,250	175
22	Ditto	342	30, 20	50	6·8	800	280	425	115
24	Ditto	229	20, 20, 10	50	4·6	615	260	470	80
31	Ditto	217	20, 20	40	5·4	1,040	135	520	50
23	1st Dec. 1926	315	30, 20	50	6·3	985	305	450	50
20	Ditto	398	30, 20, 20	70	5·7	600	250	325	60

APPENDIX V.

GOVERNMENT OF INDIA.

Department of Education, Health and Lands.

Notification No. 1493-Agri., dated the 14th of November 1925 as amended up to the 26th of January 1927.

In exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914) hereinafter referred to as the said Act, the Governor-General in Council is pleased to issue the following order for the purpose of regulating the import into British India of American cotton :—

1. In this order :—
   (i) " Cotton " includes all ginned cotton, whether baled or loose, but does not include cotton seed or unginned cotton.
   (ii) " American cotton " means all cotton produced in any part of America.
2. On or after the 1st of December 1925, American cotton shall not be imported into British India by means of the letter or sample post and shall not be imported by any other means save through the port of Bombay * (between the first of November and the thirty-first of May in any year) and subject to the following conditions :—

† [(*a*) On or before the departure of a ship carrying a consignment of American cotton for Bombay from the port from which the cotton is consigned, the consignee shall ascertain the name of the ship, the probable date of its arrival in Bombay and the number of bales of American cotton contained in the consignment, and shall furnish this information to the Collector of Customs, Bombay, not less than three weeks before the arrival of the ship at Bombay, provided that where the cotton is loaded for Bombay at Port Said or at a European port the ordinary length of voyage from which is less than three weeks, it shall be sufficient to furnish the information not less than 10 days before the arrival of the ship.]

(*b*) On arrival at Bombay, the cotton shall be disinfected in such manner as shall be prescribed in rules made by the Government of Bombay under section 5 of the said Act ;

(*c*) prior to landing the cotton the importer shall pay or agree to pay a sum at a rate fixed by the Governor-General in Council sufficient to cover the cost of fumigation.

‡ [(*d*) no vessel shall discharge American cotton during a period of rain, mist or drizzle.]

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* These words were deleted by S. 1 of Notification No. 932-Agri., dated the 19th of May 1926.
† This paragraph as it reads now was substituted by Notification No. 76-Agri., dated the 14th of January 1926.
‡ Added by S. 2 of Notification No. 932-Agri., dated the 19th of May 1926.

APPENDIX V—*contd.*

GOVERNMENT OF INDIA.

Department of Education, Health and Lands.

Notification No. 1561-Agri., dated the 26th of November 1925 as amended up to the 26th of January 1927.

In pursuance of clause (*c*) in para. 2 of the Notification of the Government of India, Department of Education, Health and Lands, No. 1493-A., dated the 14th November 1925, the Governor-General in Council is pleased to fix the rate at which the sum therein referred to is to be paid at (*e*) Rs. (3-1-0) per bale, or in cases in which the importer has failed to furnish information in accord with clause (*a*) in para. 2 of the said notification at (*e*) (Rs. 5-1-0) per bale. (*a*) [Provided that when cotton is landed at the special American cotton wharf in the Bombay docks the rate shall be (*e*) Rs. (3-12-0) per bale, or, in cases in which the importer has failed to furnish information in accordance with clause (*a*) of paragraph 2 of the said notification (*e*) Rs. (5-12-0) per bale.] This rate shall cover the cost of fumigation including the cost of loading the cotton into the barge, conveyance to the fumigation wharf or bunder, unloading from the barge after fumigation and delivery at the bunder, (*b*) [but not including Docks import charges as specified in the Bombay Port Trust Scale of Rates charged at the Docks.] Provided that the minimum fee for the fumigation of any consignment of cotton shall be Rupees one hundred and fifty.

(*c*) [2 (*a*)] In the case of samples of American cotton imported by parcel post, or as ship's parcels not exceeding 20 lbs. each in weight, the consignee shall pay a fee for fumigation of Rupees two for each parcel.

(*d*) [(*b*) In the case of sample bales of American cotton not exceeding six in number in any one consignment imported for testing purposes, the consignee shall pay a fee for fumigation of Rs. 10 for each bale.]

(*a*) Introduced by Notification No. 993-Agri., dated the 19th of May 1926.
(*b*) Inserted by Notification No. 144-Agri., dated the 26th of January 1926.
(*c*) Renumbered by Notification No. 2184-Agri., dated the 25th of November 1926.
(*d*) Introduced by Notification No. 2184-Agri., dated the 25th of November 1926.
(*e*) As amended by Notification No. 154-Agri., dated the 26th of January 1927.

APPENDIX V—*concld.*

Government of Bombay.

Notification.

Bombay Castle, 26th November 1925.

No. 4388-24.—In exercise of the powers conferred by Section 5 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Government of Bombay (Transferred Departments) is pleased to make the following rules for the detention and disinfection of American cotton, the fumigation of which is required by the notification of the Government of India in the Department of Education, Health and Lands, No. 1493-Agr., dated the 14th November 1925, and of cotton which has been in contact or proximity thereto and for regulating the powers and duties of the fumigation authority, namely :—

(1) These rules may be called the Fumigation of American Cotton Rules, 1925. They will come into force from 1st December 1925.

(2) Except as provided in Rule 5, no American cotton or any other cotton the fumigation of which is required by the notification of the Government of India in the Department of Education, Health and Lands, No. 1493-Agr., dated 14th November 1925, hereinafter called the said notification, or any other cotton which may have been in contact or proximity thereto shall be landed without fumigation* (except at any special landing place provided by the Trustees of the Port of Bombay and approved by the fumigation authority for the reception of unfumigated American cotton). Such cotton shall, on arrival at Bombay, be fumigated with hydrocyanic acid gas. Fumigation shall be carried out by the Trustees of the Port of Bombay on behalf of Government. Such cotton shall be taken overside from the vessel into barges provided by the fumigation authority and shall be conveyed to the fumigation wharf or bunder in such barges, delivery being given at the fumigation wharf or bunder only, after fumigation. The rate of discharge of cotton from vessels shall be so regulated as not to exceed the capacity of the barges provided for the purpose.

(3) Cotton other than American cotton which is imported into British India in a vessel carrying American cotton and loaded in the same hatch as any bale or bales of American cotton shall be deemed to have been in contact or in proximity thereto and shall be subject to the restrictions and conditions specified in the said notification.

(4) For the purposes of these rules the fumigation authority shall be the Collector of Customs, Bombay, or such officer as he may appoint.

(5) Samples of American cotton imported by parcel post, or as ships parcels not exceeding 20 lbs. each in weight, shall be fumigated on arrival with hydrocyanic acid gas, or such other fumigant as may be approved by the Governor-General in Council, at the Customs House.

(6) All cotton the fumigation of which is required by the said notification or under these rules shall be at the sole risk of the importer during landing, transhipment and fumigation and no liability for loss or damage due to fumigation shall attach to Government or its agents.

(7) Any breach of these rules shall be punishable with a fine which may extend to Rs. 1,000.

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* Added by Notification of the Government of Bombay, dated the 25th May 1926.

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